AD-A034 852 LOCKHEED ELECTRONICS CO INC PLAINFIELD N J F/G 13/5
THE DYNAMIC MEASUREMENT AND FUNCTIONAL INSPECTION OF SOLDER JOI--ETC(U)
DEC 76 DAAA21-76-C-0100

UNCLASSIFIED PA-TR-5005 NL

1 OF 2
AD-A
034 852

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A034 852

THE DYNAMIC MEASUREMENT AND FUNCTIONAL INSPECTION OF SOLDER JOINTS

Lockheed Electronics Company, Inc.
Plainfield, New Jersey

15 December 1976

COPY NO. 15

TECHNICAL REPORT 5005

THE DYNAMIC MEASUREMENT AND FUNCTIONAL INSPECTION OF SOLDER JOINTS

LOCKHEED ELECTRONICS COMPANY INC.

DECEMBER 1976

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

PICATINNY ARSENAL
DOVER, NEW JERSEY

The findings in this report are not to be construed as an official Department of the Army position.

DISPOSITION

Destroy this report when no longer needed. Do not return to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report 5005	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE DYNAMIC MEASUREMENT AND FUNCTIONAL INSPECTION OF SOLDER JOINTS		5. TYPE OF REPORT & PERIOD COVERED FINAL PHASE I
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) LOCKHEED ELECTRONICS COMPANY INC.		8. CONTRACT OR GRANT NUMBER(s) DAAA21-76-C-0100
9. PERFORMING ORGANIZATION NAME AND ADDRESS LOCKHEED ELECTRONICS COMPANY INC. PLAINFIELD, NEW JERSEY 07000		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS PRODUCT ASSURANCE DIRECTORATE PICATINNY ARSENAL-DOVER, NEW JERSEY 07801		12. REPORT DATE 15 DECEMBER 1976
		13. NUMBER OF PAGES 169
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE. ITS DISTRIBUTION IS UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cosmetic Inspection Criteria of Solder Joints
Destructive Evaluation of Solder Joints
Functional Dynamic Testing of Solder Joints
Problems Associated with Visual Inspection
Soldering Process Controls
Solderability Test Methods
Solderability
Cleanliness

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study evaluated the effectivenessof nondestructive and dynamic measurement techniques for determining the quality and reliability of solder joints when compared to the presently used method of visually inspecting solder joints for cosmetic appearance. The study concludes that inspection cost can be reduced and the reliability of solder joints can be best assured by quantitatively controlling soldering processes .

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. Key Words continued

Measuring Solderability by the Meniscograph Method
Dynamic Testing of Solder Joints

SUMMARY

Surveys and estimates performed during this study indicate that visual inspection costs exceed manufacturing costs for soldered connections by a factor of 4:1. This ratio becomes more alarming in light of recent test programs that reveal a significant lack of correlation between the results of visual inspection and functional tests performed on the same solder joints.

Until recently, the major research efforts associated with reducing visual inspection costs have centered around nondestructive and dynamic measurement techniques for printed circuit solder connections. All of the feasible measurement techniques were evaluated as part of this study, and all were found to be less effective than visual inspection, when used as a production type of test. There is evidence that research in this area of solder connection evaluation is diminishing as a result of dramatic break-throughs in the area of process controls.

Preliminary studies indicate that, through the proper implementation of recently developed equipment, it is possible to reduce solder connection visual inspection costs by approximately 80%, while improving productivity by as much as 55% for printed circuit board assemblies.

The approach recommended in this study to improve reliability and reduce visual inspection costs, requires the implementation of process standards for quantitatively measuring the solderability and cleanliness of the printed circuit board and its components. Only those elements of visual inspection, that have been proven by functional evaluation to correlate with solder connection reliability, are retained and utilized in the final inspection of the assembly. The study concludes that the reliability of solder joints can also be best assured by quantitatively controlling the process. The potential cost savings and reliability improvements, indicative of the controlled process approach to solder connection assembly, encourages additional effort to implement these techniques on upcoming military contracts.

PREFACE

Soldering is one of the most versatile methods for making electrical joints. Just as in the past, present acceptance of a solder joint is based upon visual criteria; i.e., using the external appearance of the joint to evaluate its quality and reliability. The criteria that have been established assume that the appearance of the surface of the solder joint is indicative of the reliability of the entire joint.

In recent years, the criteria used for the visual inspection of solder joints have come under serious attack. Responsible segments of the industry, concerned with the failure of cosmetically perfect solder joints in delivered hardware, began to doubt the validity of the criteria that were used to accept these joints when they were originally manufactured. Several independent test programs were initiated to determine the validity of cosmetic solder requirements; the published results have raised serious questions for Government agencies and members of industry alike. Many of the test findings are contrary to the requirements specified in the current military specifications on soldering. Some contractors have begun to expound the philosophy that, as long as assemblies are to be functionally tested, why expend time and cost inspecting solder joints to a set of cosmetic criteria that have not been verified by scientific tests.

Government agencies, such as Picatinny Arsenal, have become concerned about the growing costs attributable to the 100% visual inspection of solder joints and, in this regard, have awarded Contract DAAA21-76-C-0100 to study the current status of dynamic and functional acceptance of solder joints.

This study was prepared for Picatinny Arsenal under the technical guidance of Messrs. R. Gangemi and E. Cipoletti (SARPA-QA-N), with managerial review by Mr. P. Olivieri (SARPA-QA-N). Assisting in the performance of the study, were Messrs. B. Thurston, E. Golaski, D. Lee, P. Pocsi, and Mrs. M. Knight from Lockheed Electronics Company Inc., Plainfield, New Jersey, under Contract DAAA21-76-C-0100.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

TABLE OF CONTENTS (Cont)

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

SCOPE

This document is the final Phase I Report on a project to study methods and procedures for the dynamic or functional evaluation of solder joints. The work was performed by the Lockheed Electronics Company, under the direction of Picatinny Arsenal, and in accordance with Contract DAAA21-76-C-0100.

SECTION II

PURPOSE AND OBJECTIVES

The basis of the study program was a literature search to determine the status of the progress on industrial trends toward the elimination of visual inspection. It was intended to concentrate primarily on methods of dynamically or functionally measuring the characteristics of solder joints; however, as the study progressed, it became apparent that industry has abandoned these programs in favor of more universally applicable process control techniques.

The objectives of the program were to study the validity of each of the cosmetic attributes presently listed in Hi-Rel soldering specs, such as MIL-STD-1460 (MU), on the basis of metallurgical evaluations and functional test results published in the literature. Based on the findings of this phase of the study, a set of valid criteria for solder joint evaluation was to be established, and methods for automatically measuring solder joints against these criteria were to be researched and investigated in terms of technical feasibility and cost effectiveness.

Since the majority of present and future solder joints will be procured in conjunction with the assembly of printed circuit boards, the study was limited to this area of soldering technology.

SECTION III

STUDY PROGRAM - BASIC APPROACH

FAMILIARIZATION WITH COSMETIC CRITERIA OF SOLDER JOINTS

The visual inspection attributes referred to in MIL-STD-1460 (MU)* were extracted and listed separately. Each attribute was examined in terms of its relation to the metallurgy of solder bonding system, its significance in terms of actual soldering experience, and the relative feasibility of replacing the visual assessment of the attribute with a dynamic or functional measurement. The results of this examination are shown in Appendix A.

LITERATURE SEARCH

Initially, the objective of the literature search was to obtain technical or descriptive data on methods and procedures for the dynamic or functional measurement of solder joints. The intent was to evaluate techniques capable of performing electrical, thermal or other tests on a functioning piece of hardware under dynamic conditions (vibration, thermal, cycling, etc.). These techniques had to be potentially adaptable to production testing, preferably on an automated or programmed basis. Information requests, utilizing descriptors indicative of these concepts, were sent to all the major technical data sources available to LEC. A listing of all data sources purged is shown in the Reference section of this report.

RESPONSE TO DATA REQUESTS

The response to data requests was primarily in the form of bibliographies and abstracts covering every aspect of solder testing and inspection criteria. The LEC library obtained microfiche and hard copies of approximately one hundred of the most promising reports. Upon reviewing the material, it became evident that the majority of the reports dealt with laboratory testing of solder joints designed to evaluate specific modes of failure. Those reports that dealt with automated inspection tests described unique systems designed to detect a single attribute on a specific solder joint configuration. These systems are used primarily in the mass production of mechanical assemblies for other than military hardware, such as in the automotive industry.

---

*MIL-STD-1460 (MU) was issued in Sept. 1973 as a military standard for Hi-Rel soldering of electrical connections and printed wiring assemblies.

Of all the articles received in response to the data requests, only one seriously considered the prospect of evaluating solder connections based on their electrical and thermal characteristics. In a study completed for the Signal Corps in 1959, the Illinois Institute of Technology performed extensive testing and analysis of solder joints (Ref 1). A significant portion of the effort was devoted to determining the variation in measurable characteristics of good and bad solder joints under static and dynamic conditions. The findings were inconclusive in the area of electrical tests. Variations in electrical characteristics were inconsistent and depended on the joint configuration and solder quantity to a great extent. Those non-destructive tests, which offered the most promise, were in the areas of x-ray and thermal radiography; however, these techniques required expensive equipment and highly skilled visual interpretation on a 100% basis. The report recommended additional studies in the area of nondestructive testing of solder joints, but inquiries to Fort Monmouth indicated that the project was terminated.

INDUSTRIAL SURVEY

The Institute of Printed Circuits (IPC) was contacted and reported no information on production test programs specifically designed to reduce visual inspection requirements. However, it was reported that several large manufacturers such as Martin, Hughes, Rockwell, IBM and others, had made significant progress in reducing the amount of visual inspection by exercising rigid design and process controls for printed circuit soldering, Since the overall objective of the study was to minimize the dependence on subjective visual inspection, it was decided that, in addition to dynamic measurement techniques, the study would also pursue the process control concept, as significant improvements in productivity, reliability and cost had already been reported.

Some of the facilities contacted were reluctant to respond to questions concerning their Manufacturing and Quality Assurance procedures; however, strong contacts were established at Martin-Marietta, Orlando Division, and at Hollis Engineering in Nashua, N.H. The Manufacturing Research Divisions at these facilities have devoted significant effort to studying the validity of cosmetic criteria for solder joints, and were also cognizant of the activities of other facilities as a result of their mutual participation in IPC committees.

A great deal of technical data was supplied by Martin, and the additional references supplied by both Martin and Hollis resulted in a sufficiently broad base of data upon which objective opinions could be formulated.

[1]Refer to Bibliography.

SECTION IV

DISCUSSION OF FINDINGS

The following paragraphs summarize comments and conclusions extracted from technical articles and reports concerned with the evaluation of solder joints, based on functional, rather than cosmetic, criteria. Each of the major areas of study is discussed in greater detail in Section V of this report.

QUALITY ENGINEERING TRENDS

The results of the literature search and follow-up study indicate that there is growing support for the eventual elimination of solder joint inspection, especially in the assembly of printed circuit boards. Manufacturing and Quality Assurance Groups for several large users such as IBM, Rockwell and Martin Marietta Corporation concur that present day specifications covering manual and machine-made solder joints are based on adhering to a set of purely cosmetic visual criteria that are not substantiated by scientific facts. These companies have conducted numerous test programs that seem to substantiate their claim that, not only are the majority of visual criteria irrelevant to the reliability of solder connections, but that some of these attributes are actually degrading to the reliability of the termination. The number of supporting articles, test reports, and individual experts uncovered during the study indicates some merit for the conclusion that adequate adhesion area and evidence of wetting are the only criteria pertinent to the reliability of the solder connection.

BASIC PROBLEM OF VISUAL INSPECTION

Any operation for which the cost of inspection is three to four times the cost of manufacture is obviously counter-productive. This situation has persisted in the area of soldering because the inspection philosophy has been based on rejecting rather than accepting solder joints. If the amount of visual inspection were placed in its proper perspective, the savings that would be realized could be spent in areas that would further enhance productivity and reliability (Ref a). Industry members concerned with this problem have initiated programs aimed at placing the emphasis on rigid process control and functional performance requirements rather than accepting subjective visual opinion as a measure of quality and reliability. Several of the articles researched conclude that

---

[a]Refer to Telephone Conference Report at the end of this document.

improving productivity through innovation and advancement of the state-of-the-art is the responsibility of industry. Those that have been willing to act on this premise have already begun to realize the benefits. For example, Martin Marietta Corp. claims that visual inspection of solder joints has been reduced by 80%, and productivity improved by 55%, in the area of printed circuit board assemblies used on military programs (Ref 2).

METALLURGICAL ANALYSIS OF COSMETIC INSPECTION CRITERIA VS FUNCTIONAL TEST RESULTS

POROSITY

There are two primary causes of porosity in solder joints. In one case, the porosity is mainly a surface condition caused by prolonged cooling of the joint. In the other case, the porosity is the result of intermetallics of the materials being joined combining with the tin in the solder.

Porosity due to prolonged cooling is common in wave soldering operations because the ambient air has been heated in the vicinity of the solder wave. Prior to solidification, the surface of the liquid solder absorbs ambient gases, resulting in a larger grain structure. The longer the cooling period, the larger the grain structure (Ref 3).

Porosity due to intermetallics is more common in manual solder operations. Proper technique requires the operator to heat the parts being joined to the melting temperature of the solder. When the solder is applied, there is a chemical reaction that results in the formation of alloys of the materials being combined. In fact, the alloy that is formed at the interface between the solder and the surface of the metals is the bond that joins the metals together.

When a low temperature plating, such as gold, has been used, melting of the gold begins and molecules of a tin-gold alloy are formed within the liquid solder. These large tin-gold intermetallic molecules become dispersed in the tin-lead lattice, resulting in a porous appearance upon solidification. An abundance of intermetallics results in an embrittled solder joint which could fail under mechanical strain (Ref 4).

Martin Marietta has performed extensive testing on P.C. solder joints containing cosmetic defects, including surface porosity due to prolonged cooling. When joints were thermally and dynamically exercised to destruction, the analysis revealed that porous joints lasted just as long as cosmetically perfect joints (Ref 5). These results indicate that when the materials and platings used

in the wave soldering operation are known to be compatible, there is no basis for rejecting joints due to porosity. If gold plating is involved, the process can be controlled by either removing the gold (such as by wicking or by pretinning in an ultrasonic solder pot), or by carefully controlling the time-temperature relationship.

PIN HOLES AND VOIDS

These defects are most commonly caused by the escapement of entrapped gas or rosin during the cooling phase of the soldering operation. Cooling begins at the surface of joint and, immediately prior to solidification, the solder becomes pasty. Any gas escaping at this point will cause a pin-hole at the surface of the solder. If the configuration of the joint is such that the gas is permanently trapped within the termination, a void will be created in the joint (Ref 4).

These types of defects were analyzed as part of the "Martin" test program previously mentioned. When joints were dynamically tested to destruction, dissection analysis revealed that solder cracks always began at stress points outside of the actual bond area and propagated through the pure solder region.* When cracks were intercepted by voids in the solder, the cracking stopped at the void. The following analogy was used to explain this phenomenon: "When a bridge inspector discovers a crack in a section of steel, the corrective action used to stop the crack from spreading further is to drill a hole at the leading edge of the crack, and thus allow the stress to be uniformly distributed by the hole. The same principle holds true for voids in a solder connection" (Ref b). Testing demonstrated that even joints with a 50% internal void were as reliable as solid terminations (Ref 7).

WICKING

Wicking is a natrual phenomenon that occurs during the soldering of stranded wire. It describes the tendency for the liquid solder to be drawn away from the termination by the capillaries between the individual strands of the wire. Most Hi-Rel soldering specs prohibit wicking under the insulation of the wire. The attributes and methods used by inspectors to determine if the amount of wicking is within acceptable limits are somewhat inconsistent with the criteria used for other terminations. For example, one attribute that is often used requires that

*Identical results were obtained in a similar test program performed by Raytheon for the Navy in 1969 (Ref 6).

the individual strands of the wire be visible near the insulation. Since the plating used on wire strands is either tin or silver, the inspector looks for a visible line of demarcation between the solder and the wire strands in order to determine where the wicking stops. On any other type of termination, a visible line of demarcation would be judged as dewetting, and would probably result in rejection of the joint.

Westinghouse and Martin have both conducted test programs that conclude that wicking of wire at soldered connections is not undesirable, but rather, both desirable and advantageous (Ref 8). The test results at Martin were explained by the theory that on unwicked wires, the fulcrum for flexing is at the interface of the solder and the unsupported strands, resulting in a minimum bend radius during flexing and a maximum concentration of stress. On wicked terminations, the fulcrum is located under the insulation. The support of the insulation results in a much larger bend radius during flexing and thus a more uniform distribution of stress (Ref b).

PARTIALLY FILLED PLATED-THRU HOLES

In the early days of printed circuit fabrication, the predominant mode of failure was cracking of the copper in the hole due to the greater thermal expansion of the substrate material. This led to the use of "C" or "Z" wire jumpers between the top and bottom side of the board to assure that the connection would be retained. Solder plugs are also permitted as an alternate method to achieve this objective. For economic reasons, most manufacturers prefer the use of solder plugs, even though a significant amount of touch-up is required to meet the visual criteria of MIL-STD-275.* The criteria imposed require that the plated-thru hole be filled with solder to a level at least within 25% of the surface of the circuit laminate on both sides of the board. This inspection is often difficult, if not impossible, to perform on the component side of the board.

Since approximately 1967, manufacturers of raw boards have been publishing data that supports their claims that technology has resolved the problems associated with cracked plated-thru holes (PTH's). Subsequent testing has demonstrated that the plated-thru hole is now more reliable if left unfilled. The additional stresses induced by the solder during thermal cycling only tend to degrade the connection between the top and bottom of the board. The Autonetics Division of Rockwell International has conducted extensive testing that supports this conclusion. Independent studies performed by Hughes Aircraft Company and

*MIL-STD-275 is the military standard on printed wiring for electronic equipment.

NASA in the early 1970's arrived at the same conclusion (Ref 9). An AIAA report, dated Sept. 5, 1973, revealed that 70 percent of the industry was in favor of waiving the requirement of filling plated-thru holes (Ref 10).

In 1972, the Martin Marietta Co. extended the testing to determine the effect of solder fill on plated-thru holes containing component leads. In a dramatic test performed on 14 pin I.C. dips, results proved that the less solder that is present in the plated-thru hole, the longer the termination will survive. To demonstrate this fact, the I.C.'s were mounted in oversize holes. Tooth picks were forced between one side of the I.C. pins and the plated-thru holes and later removed to assure that the only solder that would be present in the hole would be whatever solder wicked up between the other side of the I.C. pin and the plated-thru hole. This condition was created for half of the pin locations for each I.C. on the board. The boards were then thermally fatigued until functional failures occurred. A chemical etch was used to remove the board material and, subsequently, the copper plated-thru holes, leaving the solder termination intact. In every case, the failure had occurred in the joints that had been filled a minimum of 75% as required by the mil-specs. In no case were cracks evident in the unfilled plated-thru hole terminations (Ref 7).

The Martin test program was significant because most of the cosmetic defects cited in MIL-STD-1460 and MIL-STD-275 were present in the test sample. All of these defects were noted prior to dynamic testing, but no attempt was made to rework them at any point in the program. The test results revealed that in all cases where wetting was evident, porosity, pinholes, voids and minimum solder had no bearing on the life of the joint. In addition, plated-thru holes that would normally be rejected for failing to meet minimum annular ring requirements showed no predominance of failure. Maximum joint life resulted when component leads were clinched, and no solder was permitted inside the plated-thru hole.

SOLDER PEAKS

Solder peaks are common to manually soldered joints where the iron used did not have adequate control over the tip temperature. Peaks are created when the tip of the iron has been cooled by thermal conduction through the solder to the hardware being joined. By the time the iron is removed the solder has also cooled to the point of being pasty and tends to stick to the tip as it is being removed. With the use of temperature-controlled soldering irons, the incidence of solder peaks has been greatly reduced (Ref 11).

Solder peaks associated with wave soldering operations are caused by the suction created between the board and the wave, as the board is leaving the wave. These peaks are more of a hazard to personnel during handling than a reliability problem. As long as the board is subjected to subsequent hi-pot testing, and the minimum clearance requirement between adjacent boards is maintained, there is no apparent advantage in removing solder peaks. In the section under Process Control, it will be shown that solder peaks of this type and, therefore, their visual inspection, can be eliminated.

EXCESSIVE SOLDER WHICH OBSCURES THE CONNECTION CONFIGURATION

It has already been established that minimum solder is preferred from a metallurgical point of view. Also, when problems occur, the troubleshooter probing the board wants to be assured that there is, in fact, a lead somewhere within the solde joint. For these reasons the requirement that the contour of the termination b discernible remains a valid one (Ref b).

NON-DESTRUCTIVE EVALUATION OF SOLDER JOINTS

Included in this area of the study were methods of assessing the quality of the solder joint by electrical test, rf noise test, ultrasonic test, radiographic analysis, and thermal measurement techniques. The premise of the study was to determine the feasibility of using a measurement technique to assess the quality and reliability of individual solder joints in a functioning assembly under dynamic test conditions.

DYNAMIC TESTING OF SOLDER JOINTS

Experience has demonstrated that programmed continuity/resistance measurements, and functional tests performed at room temperature on stationary hardware, cannot fully assess the reliability of a solder joint. Too often, assemblies fail when installed in equipment and are required to perform at operating levels of ambient temperature and vibration. This would tend to indicate some merit for performing the lower-level tests on a functional basis under dynamic conditions.

THE VALUE OF DYNAMIC TESTING

The purpose of dynamic testing is to accelerate the failure of marginal solder joints. Facilities which utilize dynamic test programs, such as Martin and Autonetics, report that temperature cycling is the most effective test for revealing defective solder joints. Intermittent opens, which are not detectable at room temperature, are often detected at elevated temperature (Ref 8). Shock and vibration are less effective in revealing marginal joints, when used as a production test, because the levels must be kept within safe limits. Excessive shock and vibration during testing will degrade all of the solder joints by accelerating the creep factor. Reduced levels of shock and vibration are effective, however, in supplementing the detection of intermittents due to loose connections and solder splashes, or other conductive foreign matter on the board.

LIMITATIONS OF FUNCTIONAL DYNAMIC TESTING FOR DETERMINING SOLDER JOINT QUALITY

All the analyses performed to date on solder joints conclude that the life of joint is related to the dynamics of its environment. There is an aging effect in solder joints directly related to mechanical stress. Joints initially passing all functional tests may fail electrically at a later date (Ref 12). Therefore, if testing is to be used as a method for determining joint reliability, as well as quality, the tests that are performed must go beyond the normal "GO" - "NO-GO" assessment. The testing must be capable of detecting anomalies in electrically acceptable joints that are indicative of future failure. It is precisely the difficulty in overcoming this constraight that has resulted in the continued use of visual inspection for Hi-Rel solder terminations. At the National Symposium on Non-Destructive Testing of Aircraft and Missile Components held in 1960, the following was stated:

> "There is one mechanism of failure that cannot be completely investigated by non-destructive methods. This is the bad weld (soldered joint, etc.)" (Ref 13).

A review of the periodicals on nondestructive testing from 1960 to the present revealed that nothing of technical significance has occurred to alter this conclusion. In the following sections it will be shown that all presently known measurement techniques fall short of determining the acceptability of solder joints.

Electrical Measurement Techniques.

Resistance

This, the most common of all electrical tests, is run on virtually all P.C. assemblies following wave soldering. The test is generally performed in conjunction with a hi-pot test. This combination of tests is most useful for detecting complete opens, shorts and miswires. If performed in conjunction with moderate vibration, a significant number of intermittents can also be detected.

In terms of a measurement technique for solder joints, there is some correlation between the value of resistance and the quality of the joint; however, the results could be extremely misleading. For example, if one or more of the elements being joined in a particular joint was gold plated, and a gold rich joint resulted, the electrical resistance of this joint would be minimal (Ref 4). The reading would not reveal the fact that the joint was embrittled and extremely unreliable. Dynamic excitement of this joint would further degrade reliability without necessarily causing failure during the test. In the case of void detection, testing has shown that, unless the avoid exists in the alloy region of the elements being joined, the void will not significantly affect the resistance measurement (Ref 1). Therefore, voids, pin holes and cracks that may be present in the pure solder region will go undetected. This was confirmed in the ITT (Ref 1) test program where an attempt was made to correlate the resistance of a P.C. solder joint with known imperfections that were revealed by x-ray photography. A direct correlation between voids visible on the x-ray and higher resistance values could not be established. (Refer to Table 1 for a summary of test results.)

Table 1. Electrical performance of x-rayed plated-thru hole solder joints

Board No	Description of Joint	Average Joint Resistance Milliohm	No. of Joints with Resistances of:			
			.0-0.1 Milli-ohm	0.10-0.25 Milli-ohm	0.25-0.50 Milli-ohm	0.05 Milli-ohm
---	No soldering, copper plating only	0.62	--	1	4	13
1-A	Normal joint	0.134	13	23	--	--

Table 1. Electrical performance of x-rayed plated-thru hole solder joints (Cont)

Board No.	Description of Joint	Average Joint Resistance Milliohm	No. of Joints with Resistances of:			
			.0-0.1 Milli-ohm	0.10-0.25 Milli-ohm	0.25-0.50 Milli-ohm	0.05 Milli-ohm
2-A	Board baked at 250°F for 25 hr before soldering. Cracks evident	0.129	10	26	--	--
3-A	Board immersed in water for 24 hr before soldering. Dewetting and voids evident	0.136	17	15	3	1
4-A	Extremely heavy flux application before soldering. Pin holes and voids evident	0.155	14	18	3	1

All indications are that only those joints that are already defective, and those joints that can be caused to fail during dynamic excitement, will be detected by resistance measurement.

Noise Level Measurement

Noise level measurements were referred to throughout the published literature as a technique used to demonstrate that joints manufactured to a particular technique were free of voids. None of the articles researched demonstrated that joints with defects other than obvious intermittents would generate detectable levels of noise. Although experience in high-quantity production of assembled P.C. boards has shown solder joints to be capable of producing excessive noise,

the investigation carried out on this program did not reveal a technique by which noisy solder joints (other than cold solder intermittents) could be made and detected on a controlled basis.

Lockheed Electronics Company (LEC) has considerable experience in R.F. noise detection and has successfully used R.F. impedance measurement as a technique for locating defective joints on a troubleshooting basis. The cavities formed by cracks or voids in the solder joint are measurable as changes in capacitance and inductance at R.F. levels. However, this technique requires isolation from all other interconnecting circuitry. In addition, the test leads must be soldered in place during the test to minimize the effects contributed by probe variations. Because of the extremely low levels of measurement involved, R.F. impedance detection is not considered feasible as a production test technique.

Practical Limitations of Electrical Test Techniques

As stated earlier, if measurement techniques are to be seriously considered as an alternate to visual inspection, they must be capable of more than merely detecting bad joints. If marginal or unreliable joints are to be located, it can be expected that the variations in electrical characteristics will be extremely small. When analyzed from a practical point of view, the problems encountered with adapting these techniques to a production type of test deteriorate the feasibility of this approach. For example, if a range of acceptable resistance values were to be established for a particular joint configuration, the measurement technique must be one that is independent of variations inherent in the copper laminate and interconnecting components. Also, the test current must be maintained constant if repeatable results are to be achieved. In order to isolate these variables, a four-wire measurement technique is indicated. Obviously, the additional printed circuitry required to provide four inputs to each solder joint on a typical P.C. board could not be tolerated. A numerically controlled probing technique would appear more feasible for solving the access problems, but it is questionable whether the probe contact resistance could be controlled to a sufficiently low level. The use of high frequency techniques is less feasible because the critical variables cannot be controlled. Normal variations in the placement of components would mask out any inductance variations associated with the solder joint. Dynamic test conditions would result in the movement of components and leads and further aggravate these variations. Any junction type of device (diodes, I.C.'s etc.) in the same circuit with the solder joint would mask out the capacitance variations associated with the solder joint. These limitations tend to rule out the feasibility of a functional or production type noise measurement technique.

Thermal Measurement Techniques

Thermal measurement techniques eliminate, for the most part, the problem of component interaction on the observed measurement. Two basic approaches were discussed in the literature. One method utilizes heat detection techniques based on observing the rate of infra-red radiation from an external heat source. An attempt is then made to correlate the measurement to the metallurgical integrity of the joint. The second method relies on the measurement of the heat generated by the actual circuit currents on a functional assembly. This technique produces a thermal "map" of the entire assembly and allows for the detection of "hot spots" anywhere in the circuit.

Infra-Red (I.R.) Detection Using External Heat Source

The advantages of this approach are that it is readily adaptable to a production type test utilizing numerically controlled optical scanning devices. The detector output is compared with readings obtained from an acceptable (standard) board permanently stored in memory (Ref 14). Surface defects such as porosity, pin holes, and voids can be detected by this method.

The disadvantage with this approach is that the detector cannot distinguish between variations due to surface defects in the solder and variations caused by slight differences in the configuration of the joint. The shape of the solder fillet, placement of the component lead, and shading from adjacent components, all affect the level and direction of radiated energy.

This method of inspection is extremely effective for a "GO" - "NO-GO" type of determination, such as in the inspection of location and size of plated-thru holes in raw P.C. boards. It is not considered a practical approach to P.C. solder joint inspection at the present time.

I.R. Detection of Circuit Defects in Functional P.C. Assemblies

I.R. detection of heat generated by a functional piece of hardware is, by far, a more meaningful but more costly approach to non-destructive testing. Performing functional tests at the subassembly level on P.C. boards of present day complexity generally requires a sophisticated software program and computerized test equipment. This type of inspection is becoming popular in the I.C. industry, where production quantities are sufficient to offset costs. It has also been used successfully to supplement visual inspection on man-rated space hardware programs (Ref 15).

A typical detection system combines an infrared detector with microscopic optics. The detector scans the functioning assembly and makes a thermal profile. The profile can consist of a magnified image recorded on video tape or film, or it can be fed directly into a computer for correlation with previously stored acceptance data.

The latter method still suffers from the problem of not being able to account for all the variations experienced between seemingly identical solder joints. As a result, a significant amount of visual inspection is still required to resolve marginal readings.

A visual inspection of the image itself is considered more reliable. For example, a hidden solder crack, that may later result in failure, will show up under thermal examination because the heat flow will be uneven across the crack. This will show up on the image as a contrast between the color of the crack and the circuitry on either side of the crack (Ref 16).

The disadvantage of this method of inspection is primarily one of cost. To be truly effective, a visual analysis of the thermal image is still required. The visual inspection skills are more demanding; therefore, the cost of visual inspection is likely to increase. Component procurement costs are also affected because only minimum variations in component impedance can be tolerated if power dissipated in solder joints is to be maintained within repeatable limits.

Although this form of I.R. detection is considered superior to present visual inspection techniques, it is not considered a practical approach for the type and quantity of P.C. assemblies normally encountered in military hardware programs.

Ultrasonic/Acoustical Measurement Techniques

Ultrasonic and acoustical testing utilize the acoustical impedance of an object in order to make a determination as to its structural integrity. This technique has proven highly effective in the detection of minute cracks and voids in structural members on aircraft. In principal, the technique used is similar to sonar. A high frequency signal (30 MHz or greater for ultrasonic levels) is transmitted through the material by means of a transducer. Any discontinuity in the material will impede transmission of the signal through the material. This will result in a portion of the transmitted energy being reflected back to and detected by the transducer (Ref 17).

Considerable effort is currently being applied to studies of echo pattern recognition. The studies are aimed at determining the dynamic echo properties of classical flaw situations, so that the size, type and severity of flaws can be identified and evaluated by correlation techniques.

At present, the state-of-the-art in ultrasonic and acoustical testing is not a viable method of evaluating production solder joints. Solder quantity, fillet shape, thickness of the alloy (bond) region, and variations between the materials (solder, component leads, plated-thru hole, etc.) all present different impedance characteristics to the transmitted signal. It is likely that even a gross flaw would be masked by the effects of these discontinuities.

Pulsed Laser Harmonic Detection Techniques

Although specific articles could not be located on this topic, optical and R.F. experts at LEC have been aware of experiments being performed in this area. The potential application of this technique is extremely limited, in that it is only useful for locating intermittents and cold solder joints. The advantage is that the circuit need not be operational during the test. The theory behind this approach is based on experimental findings that reveal that, when two conducting elements are separated by an intermolecular gap, the elements are capable of exhibiting diode junction characteristics. More interestingly, the defective solder joint can be made to behave like a light emitting diode.

The test method consists of focusing an infrared laser source through a fiber optics light guide on to the surface of a joint, while varying the ambient temperature. If the joint is defective at some point, the separation of contacting surfaces caused by thermal expansion (or contraction) will be optimum. The junction thus created will generate higher order harmonics of the test frequency. Those within the ultraviolet frequency spectrum that are reflected through the fiber optics bundle can be detected, thereby indicating an intermittent connection.

The literature study and vendor survey did not uncover any evidence of a serious effort to develop this theory into a practical flaw detection system. However, the Laser Research Group at Lockheed Missiles and Space Co. anticipate additional studies will be conducted in the future.

Other Non-Destructive Measurement Techniques

The literature study also considered other radiographic (x-ray, beta-ray, neutron and proton) techniques, as well as optical scanning of fluorescent penetrant residues for detecting pin holes, voids and cracks. These techniques will not be discussed in this report, because of various limitations that render them ineffective as a production type test. A summary of these techniques is shown in Appendix B.

SECTION V

ANALYSIS OF STUDY FINDINGS

There is currently a major effort underway within the industry to reduce the total cost of delivered hardware. The primary motivating force behind this and similar efforts has been the growing concern for the U.S.'s ebbing competitive status among the industrial nations of the world. Government statistics indicate that the U.S. has slipped to seventh place amoung the industrial nations in terms of productivity growth. (See Figure 1.) Manufacturing facilities have been analyzing their operations and identifying those areas where significant cost improvements can be made without sacrificing product quality and reliability. The area of soldered connections has been overwhelmingly identified as a major contributor to counterproductive measures. This conclusion is not based solely upon judgement. The industry has conducted the necessary tests to validate these claims.

A HISTORY OF SOLDER JOINT TECHNOLOGY (See Figure 2.)

Following WWII there was a natural shift in technology towards the development of commercial products. During this period, the military was engaged in the development of computers to aid in the design of the next generation of weapon systems. The vacuum tube was still the heart of all electronic circuits. Component failures were so numerous during this period, that relatively little attention was paid to solder joints.

It wasn't until the early 1950's that the soldering problem was seriously analyzed. Metallurgists were convinced that highly reliable joints could be produced if critical parameters such as time and temperature could be controlled. It seemed unlikely that this goal could be achieved as long as the human element (manual soldering) remained involved. Therefore, studies were initiated to discover a method for reducing the number of soldered connections. Massachusetts Institute of Technology (MIT) was awarded a government grant to study the problem. They became aware of the "Eisler" patent which described a method of bonding flat copper conductors to the wings of aircraft as a method of retarding ice formations at high altitude. MIT obtained rights to utilize this concept for development of the single-sided P.C. boards. By 1953, MIT had successfully produced a simply configured P.C. board utilizing a copper pattern bonded to a 1/4-inch phenolic substrate (Ref g).

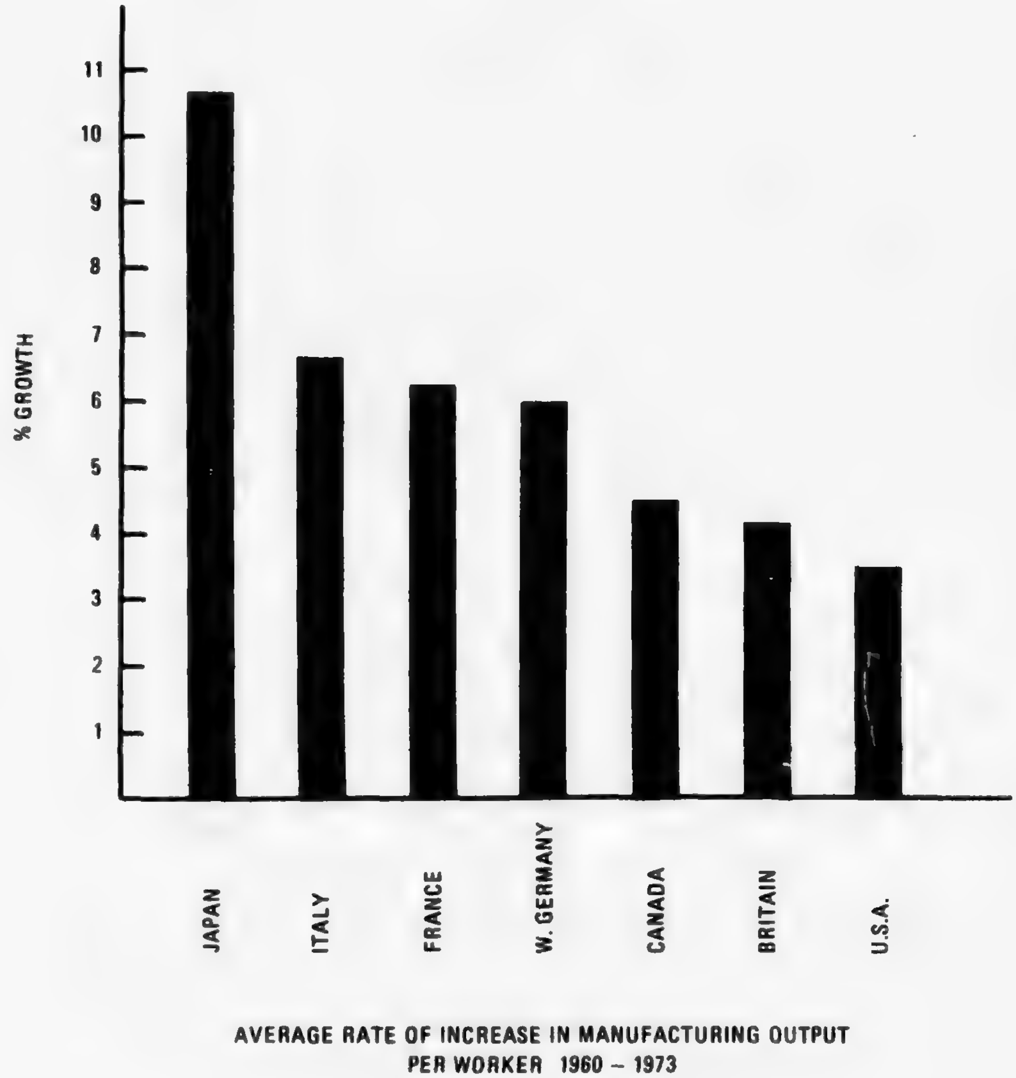


Figure 1. Productivity growth of major industrial-free nations

In 1954, Electrolab Inc. was one of the first to offer a P.C. line for commercial users. The board consisted of a bonded pattern on 1/16-inch paper based phenolic laminate. The patterns were dip coated with solder to enhance solderability after storage. The first large commercial use was for crossover networks in the growing TV industry (Ref g).

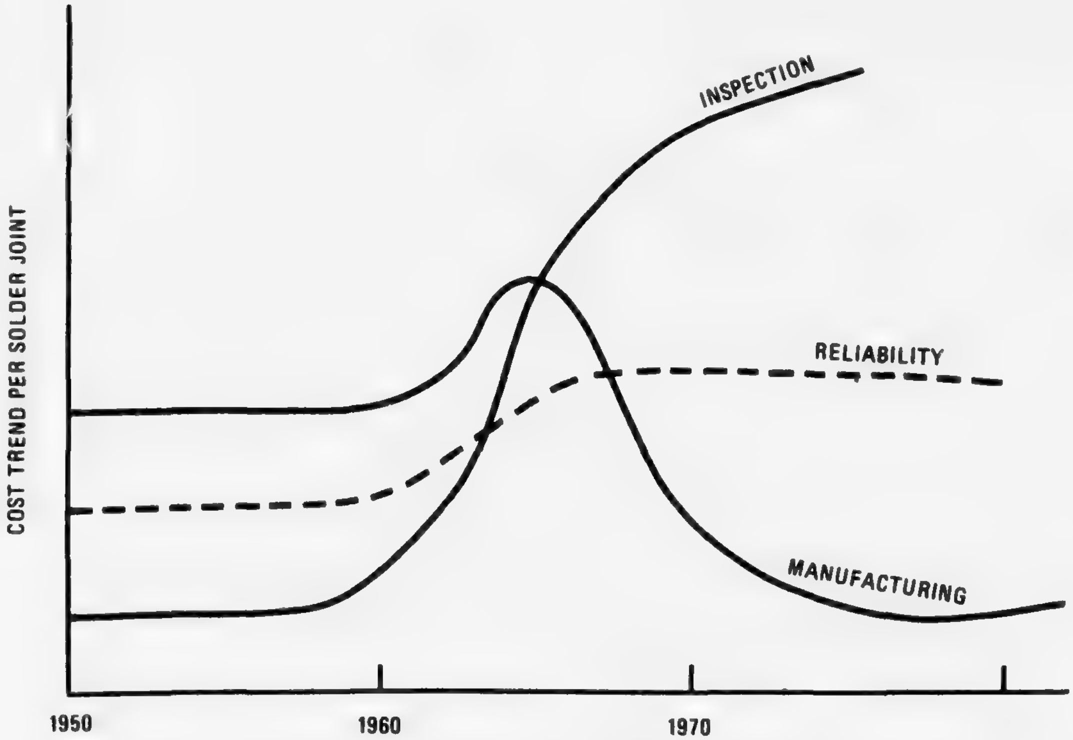


Figure 2. Solder joint costs vs reliability

Solder dipping had become the standard method of soldering P.C. components. Results were inconsistent due to variations in thermal mass between joints and lack of adequate cleaning and fluxing. The majority of joints required manual touch-up, and controlling dross in the solder pot was an annoying problem (Ref f).

Around 1955, the first wave soldering machine was demonstrated in England. Initial results were poor due to extensive icicling and bridging of conductors.

U.S. firms were generally skeptical about the potential of this system, but in 1960, an American Company (Addawave Inc.) obtained license rights from the Fry's Co. of England to manufacture a wave soldering machine in the U.S. Addawave was unsuccessful in resolving the technical problems and was soon forced to sell its rights (Ref g).

In the early 60's the first inclined conveyor was introduced. This technique greatly reduced the bridging problem associated with horizontally soldered boards and thereby enabled wave soldering to replace dipping as the standard method for P.C. boards (Ref f).

During this same period (1955 - 1960), circuit complexity had continued to increase and board manufacturers were offering double-sided boards with top and bottom pattern interconnected with eyelets. The eyelet concept presented costly manufacturing problems and reliability was poor (Ref g).

In 1956 rights were obtained to utilize the "Narcus Patent"* to develop a method of producing plated-thru holes. It took approximately 12 years to resolve the reliability problems associated with plated-thru holes (Ref g). Stress, due to nonuniform plating thickness, created cracks under thermal dynamic conditions. Solder plugs or "C" wires are still required by the MIL-Specs to provide a redundant connection between the top and bottom of the board.

Improvements in the manufacturing process have resolved these problems, and the suppliers now claim that solder plugs degrade the plated-thru hole. "C" wires may be similarly degrading, because of the additional (unwanted) solder that wicks up into the plated-thru hole.

By the mid 60's, the major problems associated with P.C. wave soldering had been resolved. The use of tinning oil within the solder enabled closer conductor spacing without bridging, wider waves enabled increased production quantities, and deeper waves eliminated the need for clinching component leads (Ref g).

It was at this point in the development of the technology that productivity improvements were retarded due to a reassignment of objectives. The U.S. had recently embarked on a space program that would include manned flights, and reliability became the keyword of the industry. However, the method used to achieve the required reliability was not necessarily one of advancing the state-of-the-art; in many cases, the approach was one of repeated 100% visual inspection and costly functional testing. Such was the case with solder joints. The philosophy became one of "Reliability at any Cost." Elaborate detailed specifications and 100% visual inspection of components and assemblies were mandatory to assure mission success.

---

*Dr. Narcus obtained a patent for a method of plating on a non-metallic surface. The technique was developed by Narcus for the bronzing of baby shoes.

Since cost was not a serious limitation, a unique design philosophy ensued. If an anomaly is evident in a particular piece of hardware, and if it is possible to produce the item without the anomaly, the item should be rejected. NASA developed soldering requirements that specified everything that the inspector should look for to reject a solder joint. Acceptance was based on survival rather than an understanding as to what constitutes a good solder joint.

Since the space program was extremely successful from a reliability viewpoint, other government agencies have assumed that NASA specifications are synonymous with reliability. Present Hi-Rel soldering specs are not significantly different from the original NASA soldering specs. Unfortunately, many have forgotten that these specs were created for a program where cost was a secondary consideration. The result is that convetional hardware programs are paying for NASA level solder joint inspection criteria to reject, rather than accept, solder joints.

Since the mid 60's, military contractors have continued to spend more dollars inspecting and rejecting solder joints. The emergence of double-sided and multi-layer P.C. boards doubled visual inspection costs by requiring both sides of the board to be inspected. The situation has reached the point where the cost of making a solder joint is almost insignificant, yet the cost of inspecting it represents a major portion of the end item cost (Ref b).

The commercial electronics market in the U.S has probably suffered even more as a result of reliability concepts carried over from the space program. Manufacturers of commercial goods have always looked to the military for technological advances and reliability concepts, when applicable. TV and audio equipment manufacturers, as well as computer and other leased equipment suppliers, depended on reliability in order to maintain a competitive "good will" position. However, the cost of reliability was destroying productivity, and by 1970 Japan had taken the lead in several important segments of the industry. For years American manufacturers had mistakenly blamed the difference in labor costs for Japan's competitive gains; however, the American consumer was also associating Japanese products with quality and performance (Ref f).

A tour of Japanese manufacturing plants in the early 70's opened the eyes of many American manufacturers. They found that instead of pursuing NASA level inspection techniques, the Japanese had invested in making a better product that, therefore, did not require as much inspection (Ref b). It was learned that improved tinning oils and improved solder wave pumps had

significantly increased production rates. Fully activated soldering flux had been used exclusively since the early 60's. Automatic lead cutting after soldering has also been widely used for the past ten years (Ref f).

As a result, American manufacturers were faced with the prospect of catching up. IBM has already switched to water-soluble fluxes at some of its manufacturing facilities (Ref f). Other manufacturers are approaching the problem more cautiously and have invested in solder joint study programs. This is evident from the published literature covering numerous studies on the metallurgy, reliability, testing, and inspection of solder joints.

The conclusion most often reached as a result of these studies is that the quality and reliability of a solder joint cannot be detected by the eye, but must be predetermined by effective quality control before the soldering is done. Several studies have even concluded that visual inspection of solder joints is worse than no inspection at all, because it invariably calls for touch-up or rework which only degrades the reliability of the joint. In other words, if the real objective is to assure the reliability and quality of solder joints, visually inspecting it is several steps too late. The reliability must be built in.

It is this philosophy that has enabled those that have approached the problem from a producibility, rather than a testing, view point, to achieve significantly greater success. The literature clearly indicates that all efforts to measure solder joint reliability by non-destructive production testing techniques have failed to contribute to improved reliability or reduced inspection costs. On the other hand, there is considerable evidence that by exercising rigid control over available processes and materials, it is possible to improve reliability while significantly reducing inspection and end item costs.

INDUSTRY'S ASSESSMENT OF THE COSMETIC SOLDER JOINT

The following paragraphs summarize the results of studies and test programs conducted by major suppliers of military hardware. All of these programs were designed to establish meaningful criteria for the manufacture and/or inspection of solder joints.

ILLINOIS INSTITUTE OF TECHNOLOGY

This study program was performed for the Army Signal Corps at Fort Monmouth, N.J., and was completed July 15, 1959 (Ref 1). The object of the program was to establish design criteria for printed wiring solder joints based upon the behavior of the materials involved, joint stress distributions, strength

and environmental considerations. After extensive metallurgical and functional testing, the program was terminated without arriving at any definite conclusions as to what consitutes a good solder joint. Although the program failed to meet its objectives, the findings were valuable from an analytical point of view. A review of the final report indicates that the program failed primarily because supposedly defective joints failed to respond any differently than cosmetically acceptable joints. This unanticipated phenomenon occurred in both environmental testing and in non-destructive measurement techniques. As a result, the findings were inconclusive and the report recommended additional study to determine the mechanical and electrical properties of solder joints.

The significance of this program is that there was evidence, as early as 1959, to indicate that the criteria being used to assess the quality of solder joints were subject to question. Unfortunately, this possibility was overlooked and the project was terminated.

NATIONAL RESEARCH COUNCIL - OTTAWA, CANADA

The objective of this test program was to determine the strength of various configurations of solder joints. All test samples had been visually inspected to be free of surface defects; however, there was sufficient variation in the results to generate the following conclusion.

> "These results are probably sufficient to show that visual inspection cannot, in general, detect the quality of a joint made by soft soldering" (Ref 17).

Here again, there was an indication that visual inspection criteria were not being supported by scientific test results.

AUTONETICS DIVISION OF ROCKWELL INTERNATIONAL (Ref 18)

During the early 1960's Autonetics was a major supplier of printed circuit board assemblies for the Minuteman program. The production problems encountered in meeting the rigid cosmetic inspection criterion for finished joints, along with growing concern as to the validity of this criterion, led to the first major test program specifically designed to evaluate the significance of solder joint imperfections. Large quantities of solder joints, with and without various imperfections, were subjected to humidity, vibration, and aging conditions in excess of Minuteman specification requirements (see Figure 3).

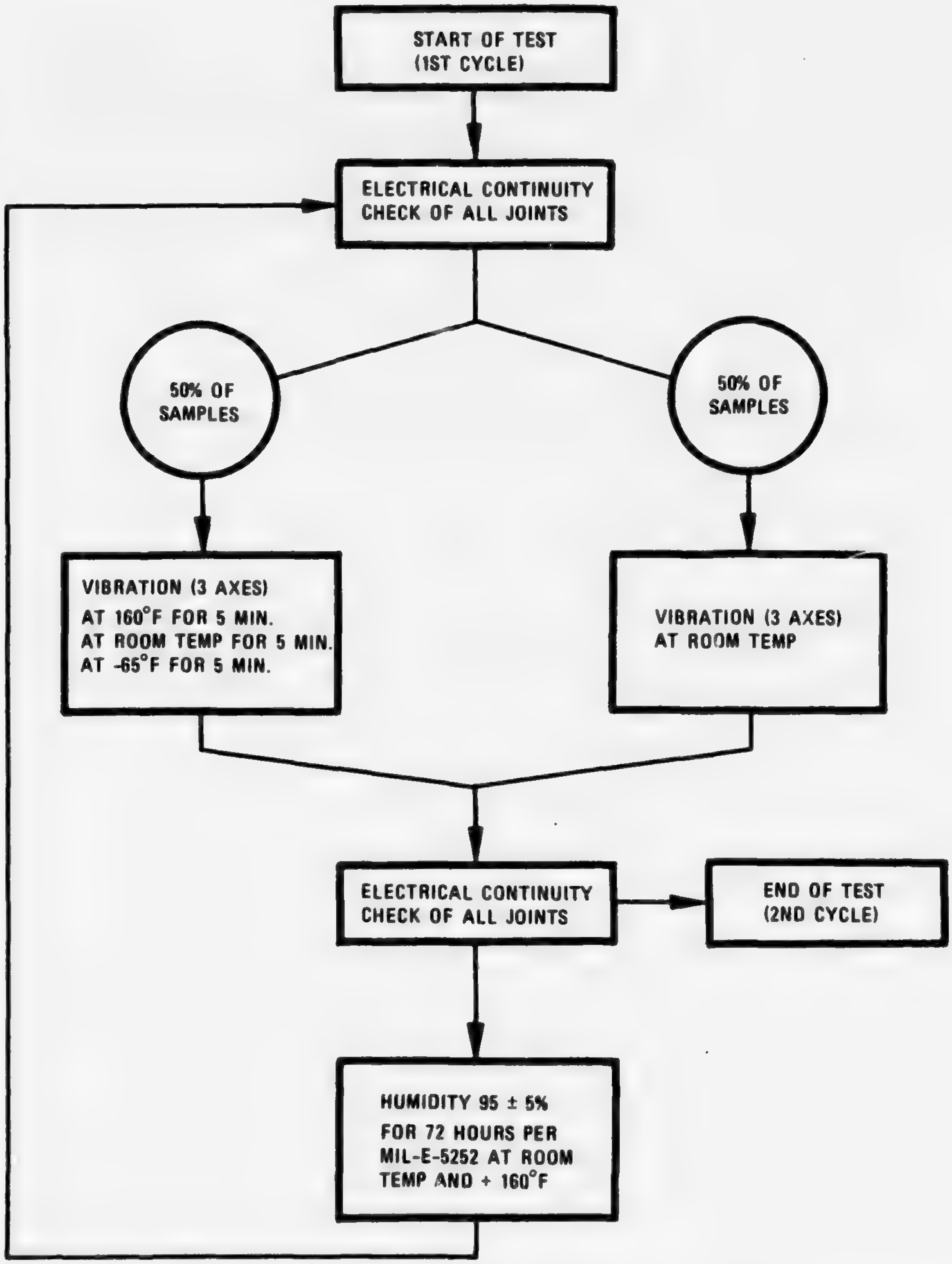


Figure 3. Autonetics test of Minuteman solder joints

The test boards were designed to simulate typical production boards. Double-sided copper circuitry on 4 inch x 8 inch x 1/16-inch G10 epoxy glass was used with .052-inch diameter copper plated-thru holes. A total of 18,181 cosmetically defective joints were included in the sample.* The types and quantity of specific defects were as follows:

a.	Partially filled plated-thru holes	1185
b.	Visible voids	1801
c.	Partially dewetted holes	5245
d.	Partially dewetted leads	4057
e.	Excess solder	3478
f.	Cold joints	926
g.	Disturbed joints	1489
	Total	18,181

The test results were analyzed to determine valid acceptance criteria for so-called imperfections that would not prevent solder joints from meeting Minuteman requirements. The conclusions that resulted were as follows:

a. Solder joints with voids, both pinhole and larger, should not fail during use, providing the plating in the hole circuitry is not defective. In addition, the lead and hole surfaces must be completely wetted and the hole, except for the pinhole or void, filled with solder. This was based on the test results in which approximately 1600 joints containing voids were subjected to environmental conditions exceeding Minuteman requirements without any failures occurring. No evidence of corrosion due to the entrapment of flux in pinholes was found. In addition, most of the solder joints tested came from boards that had been processed by marginal methods and in which the quality of the joint was considered inferior to those processed according to specification

*1200 cosmetically perfect joints (without touch-up) were also included as control samples.

b. Solder joints depleting less than 25 percent of the board thickness are acceptable for Minuteman usage, providing the plating in the hole circuitry is not defective, and the lead and hole surfaces are completely wetted. No failures occurred in approximately 1000 joints in which the depletions ranged from 20 to 80 percent of the board thickness. Seven joints that did fail were depleted more than 80 percent of the board thickness and were on unclinched component leads.

c. The results indicate that failures should not occur in solder joints with 75 percent minimum wetting of either the hole or lead periphery surfaces, providing the remaining lead or hole surfaces are completely wetted, the hole is filled with solder, and no other imperfections are present. This is based on the fact that only 26 of 3600 solder joints, with partially wetted lead and/or hole surfaces, failed. The 26 that failed had less than 55 percent wetting of the lead and/or hole surfaces.

d. Surface roughness may accurately indicate that the joint was disturbed during solidification but does not indicate that the joint is inferior in quality or lacks the ability to perform satisfactorily. None of approximately 1200 joints that were vibrated during solidification to cause disturbed solder joints failed during testing. Counting both sides of the boards, 900 of the 1200 exhibited degrees of rough surfaces.

e. Color or lustre may not accurately indicate solder joint quality and may not be indicative of the ability of solder joints to withstand conditions of usage. Most of the joints that were processed by "cold" methods had shiny surfaces, which is assumed by the industry to denote good soldering quality. Some of the joints had dull gray surfaces. An internal examination of a dull gray joint revealed that the gold plating on the copper circuitry of the holes had not dissolved, which is attributable to cold soldering. Out of approximately 1200 joints processed by cold methods, only 41 failed. These 41 had less than 10 percent solder and 10 percent wetting of the lead surfaces. The joints that did not fail had solder ranging from 20 to 100 percent of the board thickness, with various degrees of wetted surfaces. It appears that the amount of solder and degree of wetting have more influence than color or lustre on the ability of solder joints to withstand environmental conditions.

A summary of the above test results is shown in Table 2. The data clearly indicates that there is no correlation between imposed visual inspection criteria and the functional requirements of solder joints. Although the solder joints in this investigation were subjected to extreme environmental conditions, no failures occurred in joints with blemish-free surfaces, pinholes, large voids, and disturbed surfaces. Failures that did occur were with inferior joints that undoubtedly would not be acceptable by any standards.

Table 2. Summary of Autonetics cosmetic solder joint (Minuteman) test results

Type of Defect	Number of Joints	Number of Joint Failures
Pinholes Clean	1200	0
Pinholes (with Entrapped flux)	51	0
Large Voids	550	0
Partially Filled Plated-Thru Holes	1000	7 *
Partially Dewetted Holes	1200	1 **
Partially Dewetted Leads	1200	16 **
Partially Dewetted Holes and Leads	1200	9 **
Disturbed Joints	1200	0
Cold Joints	1200	41 ***

*Six of the holes less than 20% filled with solder, other hole only 5% filled with solder.

**All holes less than 35% filled with solder.

***All joints were cosmetically perfect on the surface but analysis revealed holes only 10% filled with solder and badly dewetted.

Another important finding resulted as part of the analysis of pinholes. One of the objections to pinholes is that flux and other contaminates could be trapped and eventually cause corrosion. To evaluate this possibility, more than fifty joints were soldered using a concentrated fully activated (RA) flux. The pinholes were created by using excessive amounts of the flux. No special cleaning techniques were used and, following extended humidity testing (the board was not conformally coated), there was no evidence of corrosion.

With regard to the overall test program, it should be noted that components were mounted in plated-thru holes with straight (unclinched) leads. Where failures did occur, only 20% or less of the hole was filled with solder. Failure would probably not have occurred if the leads had been clinched and soldered on the bottom side of the board, regardless of the amount of solder in the hole.

The results of the study program were rather conclusive in demonstrating that the cosmetic imperfections on the surface of a solder joint have no bearing on the reliability of the joint. However, the question of whether or not plated-thru holes should be filled with solder was not fully resolved. With the emergence of multilayer boards the significance of the question was greatly increased.

In 1966 it was established by the industry that temperature cycling was the most effective method for measuring P.C. board performance and reliability. Autonetics embarked on an extensive test program to determine the reliability of plated-thru holes (Ref 10). Initial tests indicated that a primary cause for failure was stress points in the plating due to non-uniformity within the hole prior to plating. A change in the process eliminated this problem, and so the study continued to investigate the effect of hole size and solder plugging on hole reliability. A test was performed on twelve multilayer boards designed by the Institute of Printed Circuits. Each board contained 276 plated-thru holes of three different size (.020, .030, and .040-inch) diameters. None of the holes were filled with solder. The boards were thermally stressed to the levels shown in Table 3. Each circuit was scanned for continuity twice each minute throughout the test. There were no failures. The test concluded that a controlled process for manufacturing plated-thru holes was preferred to solder plugging from both a cost and a reliability viewpoint.

Table 3. Autonetics - thermal stress of plated-thru holes, test parameters (Ref 10)

Sample Quantity	Temp °C	Time* Min.	Temp °C	Time* Min.	Cycles	No. of Failures
3	-40	30	+75	30	10	0
3	-55	30	+100	30	20	0
3	-65	30	+125	30	20	0
3	-65	30	+150	30	40	0

*Transfer time between hot and cold chambers was one minute maximum.

Solder plugging has been required by the military because it is hoped that the solder will provide a redundancy in the event that a plated-thru hole develops a crack that could result in an intermittent open circuit. However, tests have shown that solder filling may induce stresses that result in the separation of the plated hole wall from the substrate. The conclusion that solder plugging may degrade plated-thru hole reliability has been recently supported by RADC and NASA (Ref 10).

The study also concluded that the specifications governing the manufacture of raw boards range from inadequate to unrealistic. Far less emphasis is placed on the inspection of raw boards than on the final assembly. Table 4 illustrates a comparison of the criteria specified in MIL-P-55640* to the requirements demanded by Autonetics on two typical programs.

The results of the Autonetics studies tend to confirm the premise that the major effort toward improving solder joint reliability must be concentrated in the processes that occur prior to soldering.

Table 4. Mil-spec vs Autonetics plated-thru hole quality requirements (Ref 10)

Characteristics	MIL-P-55640	Program B	Program A
Copper plating thickness	0.001 in. minimum avg; isolated thick-thin sections not to be used for averaging	0.0015 in. absolute minimum valve	0.0013 in. minimum avg; isolated spots of 0.001 in. no longer than 0.010 in.; combined total
Plating voids	Three totaling no more than 5% of wall length	None permitted	0.020 in. maximum. None permitted

*MIL-P-55640 specifies the requirements for multilayer P.C. boards using plated-thru holes.

Table 4. MIL-spec vs Autonetics plated-thru hole quality requirements (Ref 10) (Cont)

Characteristics	MIL-P-55640	Program B	Program A
Breaks in epoxy wall (drill tear-out)	Does not specify	None permitted	None permitted
Inclusions of foreign material	Does not specify	None permitted	None permitted
Separation of conductor interfaces	None permitted	None permitted	None permitted
Cracking	None permitted	None permitted	None permitted
Hole-wall smoothness factor	Does not specify	0.67 minimum, Smoothness factor = $\frac{\text{thin plate thickness}}{\text{thick plate thickness}}$	Does not specify
Surface plating thickness	Does not specify	0.0008 in. minimum	0.0008 in. minimum
Quality of plating, cross-section	50-100X magnification	300X minimum magnification	300X minimum magnification
Solder plugs	After assembly	None	None

WESTINGHOUSE ELECTRIC CORPORATION

In 1965 Westinghouse completed a study of the effect of wicking on soldered wire terminations (Ref 8). A total of 600 stranded wires were flex-tested to destruction. The wires were soldered to standard connector pins using MIL approved soldering techniques with the exception that no attempt was made to control wicking for most of the sample wires (the exact quantity of wicked vs unwicked wires was not cited in the referenced article). The sample wires were vertically supported under approximately 1 in/lb of spring tension and flexed 60° at the rate of 45 flexes-per-minute. The test results shown in Table 5 demonstrate that wicked wires exhibit a longer flex life than unwicked wires.

Table 5. Westinghouse flux test results for wicked vs unwicked wires (Ref 8)

Total Flexures for Wicked Wires	250,956
Total Flexures for Unwicked Wires	41,876
Average Flex Life of Wicked Wires	418
Average Flex Life of Unwicked Wires	70
Average Flex Time to Destroy 20 Wicked Wires at 45 Flexes/Min	82 Min
Average Flex Time to Destroy 20 Unwicked Wires at 45 Flexes/Min	17 Min

The test was repeated with similar samples subjected to three cycles of vibration in two axes. Each cycle consisted of 30 G's, from 50 to 2000 Hz for 11 minutes, of which 5 minutes was at the resonant frequency. Neither wicked nor unwicked wires failed, indicating no adverse effect from wicking.

LOCKHEED MISSILES AND SPACE COMPANY (LMSC)

In April of 1965, LMSC completed a study of inspection methods for soldered connections (Ref 19). The study was primarily an evaluation of the current literature on inspection and non-destructive test techniques. The study concluded that visual inspection was ineffective as a technique for determining joint reliability. The report recommended that emphasis in quality control be shifted to controlling the process rather than merely viewing the end result.

"Quality Control personnel should be educated to recognize the fact that the quality and reliability of a solder joint cannot be detected by the eye, but must be predetermined by Quality Control before the soldering is done."

The study considered three methods of non-destructive techniques for evaluating joint quality:

a. Fluorescent and Dye Penetrant Inspection. This method is useful only as an aid to the visual inspection of surface defects. By making defects luminous under ultraviolet light, the detection of such defects is enhanced, less time consuming and less dependent on inspector skill and judgement. However, it has already been established that the majority of surface defects detectable by this method (pinholes, porosity, etc.) are not detrimental and, therefore, the value of this technique is greatly diminished.

b. Electrical Resistance Method. The study concluded that electrical continuity and other electrical factors of a new soldered joint are deceiving, in that an unreliable joint will be indicated only with aging. (Accelerated aging tests must be considered destructive, since the reliability of all the joints in the assembly is degraded by the test.)

c. Radiography. The study concluded that this technique was not suited to a production type of test because the technique requires a precise and meticulous operation. Also, to be useful, all joints must be uniform in thickness and the exposure must be made straight through the joint.

Recent conversations with LMSC Quality Assurance and Manufacturing Branch Supervisors indicate that the conclusions reached in the 1965 study are still valid, and the approach being advocated by LMSC is to integrate the quality control function with the process control of the soldering operation (Ref c, d, and e).

MARTIN MARIETTA CO., ORLANDO DIVISION

Based on the literature, it is evident that Martin Marietta is a leader in the field of soldering technology. Solder joint study and test programs have been performed on a continual basis throughout the past decade.

In 1966, Martin published the findings of its investigation of wicking and confirmed the results of the Westinghouse test program (Refer to page 41).

The Martin test was similar to the Westinghouse test, except that the flex angle was increased to 120° and the rate of flexing was reduced to 22 cycles/min. The test results demonstrated that normally wicked wires survived significantly longer than unwicked wires (Ref 20) (see Figure 4).

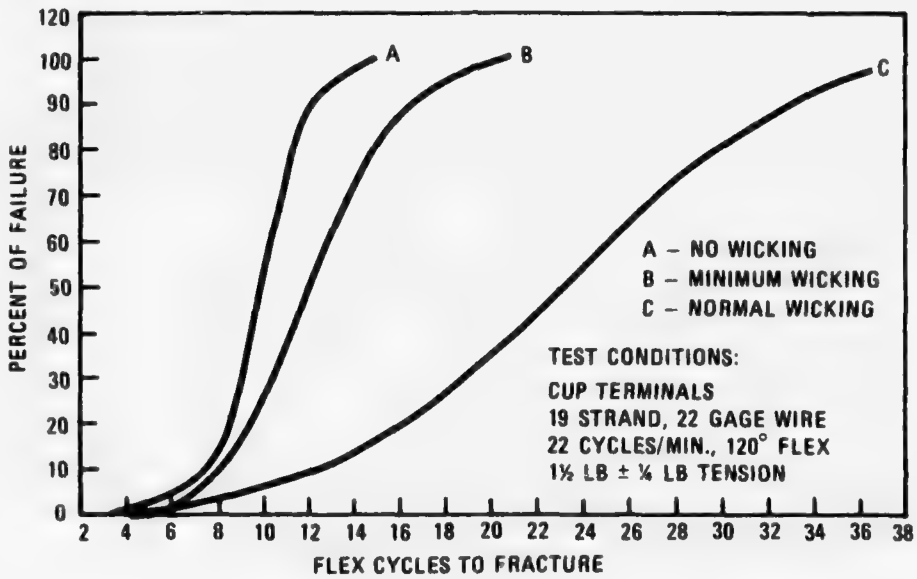


Figure 4. Martin test results on wicked wires

In 1969 Martin completed a test program to determine the correlation between currently rejectable imperfections found in typical P.C. solder joints and the functional reliability of these joints under extreme environmental conditions (Ref 21). A total of 36 standard P.C. assemblies containing all of the commonly used active and passive lead-mounted components were assembled under normal production conditions. The boards were visually inspected and more than 3,500 imperfections, rejectable in MIL-Spec criteria, were noted and recorded. The boards were environmentally tested in accordance with MIL-C-21097B,* using

*MIL-C-21097 is a P.C. connector spec, however, the environmental tests are consistent with final P.C. assembly requirements.

the applicable methods of MIL-STD-202C.* The tests included humidity, salt spray, mechanical shock, thermal shock and vibration. The testing was severe enough to induce functional failures; however, failure analysis revealed that none of the failures were associated with cosmetic defects. Where failures did occur, the plated-thru was completely filled with solder (as required by MIL-Specs), and led to a subsequent investigation of this requirement.

The test results clearly showed that thermal shock cycling was the most severe environmental test for solder joints. Another test program was initiated, again using standard P.C. hardware, to concentrate specifically on the effects of thermal shock cycling of visually inspected solder joints (Ref 22). The completed sample boards were inspected by Q.A. and by Manufacturing. Joints were classified as follows:

a. Rejectable Quantity	87
b. Questionable Quantity**	133
c. Acceptable Quantity	2238

The boards were automatically shock cycled between -100°F and +200°F (45 seconds at each extreme and 15 seconds at room temperature between extremes). The test, which was more severe than any MIL-Spec environmental requirement, was limited to 1000 cycles. The following is a summary of the test results:

a. Voids. Twenty-two joints had been rejected due to voids. The first failure (crack) occurred at the 900th cycle. Three additional joints failed at the 1000th cycle. Eighteen joints survived the full test.

b. Excess Solder. Twenty-three joints had been rejected due to excess solder. Thirteen of these joints failed between 600 and 1000 cycles.

c. Improperly Clinched Leads. Twelve joints were rejected for leads not clinched parallel to the circuit. One failed at 500, one failed at 900, and three failed at 1000 cycles. Seven joints survived the full test.

*MIL-STD-202 defines the methods for testing electrical component parts.

**Rejectable to MIL-Spec cosmetic criteria but acceptable on the basis of Martin Manufacturing experience.

d. Test Probe Holes. Eight joints had been intentionally gouged with a test probe to simulate a common form of poor workmanship. Six failed between 900 and 1000 cycles. Two survived the full test.

e. Dewetting. Ninety-four joints were questionable due to some dewetting on the pad. Eleven of these joints failed between 800 and 1000 cycles. Eighty-three survived the full test.

f. Eyelet Joints. In addition to plated-thru holes, approximately four hundred joints were made using eyelets in lieu of plated-thru holes. Two hundred of these were solid barrel eyelets and two hundred were split barrel eyelets. Seventy-three of the solid eyelets had been questionable due to micro cracks before testing. Sixty-four of these joints failed between 10 and 500 cycles. Ninety-two of these joints had been rejected due to pin holes. Eighty-one of these joints failed between 10 and 800 cycles. None of the split eyelets containing anomalies failed the test.

In summary, the test results indicated that only twelve of the eighty-seven rejected joints (13.8%), and 133 questionably rejected joints (24.8%), failed the test, while 758 of the 2238 acceptable joints (34%) failed the test.

This program was designed to subject solder joints to an environment that depended on joint quality for survivability. The purpose of the test was to determine if visual inspection could accurately predict the outcome. The test results clearly indicate that there was absolutely no correlation between the visual inspection and the final test results. (Refer to Table 6.)

Table 6. Martin Marietta thermal shock cycling to typical operational hardware levels, test results (Ref 22)

Visual Inspection Results		Quantity	No. of Failures	Percent of Total
Rejected Joints		87	12	.48
Questionable Joints		133	33	1.34
Accepted Joints		2238	758	30.70
	Total	2458	803	32.60

NOTE: 32.6% of the solder joints failed during thermal shock cycling. Of these, 30.7% had been accepted by visual inspection.

FOLLOW-UP INVESTIGATIONS

It became evident from the preceding test that visual inspection was inadequate for determining joint quality. Martin, therefore, conducted an investigation to determine if cracked joints could be detected by electrical test. Three sample boards were assembled. Two were subjected to 200 thermal shock cycles to induce minor cracking. The third board was used as a control sample. The boards were examined by a Components Evaluation Laboratory and subjected to electron microprobe analysis. The investigation revealed that the electrical resistance of cracked and uncracked joints was similar. The microprobe analysis also concluded that the chemical composition and electrical conductivity of cracked joints were identical to normal joints. This analysis revealed that simplified and cost effective electrical tests would also be ineffective in locating potential failures.

LIFE TESTING

At this point in the Martin solder joint investigations, six P.C. assemblies which had been placed on life test in 1960 had accumulated in excess of 4000 hours of storage life thermal cycling conditioning. During the test, they had been cycled between -65°F and +125°F once every 24 hours. Each board had approximately 75 solder joints, of which an everage of 30% had been rejected by visual inspection. Each of the boards was functionally tested and there were no failures. This equates to 1.8×10^6 joint hours, of which 30% had been rejected by visual inspection, without failure.

THE EFFECTS OF SOLDER FILL ON PLATED-THRU HOLE RELIABILITY

The previous test programs had led to the conclusion that the majority of cosmetic defects rejectable to existing visual inspection criteria had no correlation to the functional reliability of a solder joint. However, the fact that significantly more cosmetically perfect joints failed than rejected joints raised serious questions as to the validity of all previous concepts concerning reliable solder joints. Martin initiated a study program in 1972 to determine the cause of cracking in cosmetically acceptable solder joints (Ref 23). A second review of the previous test data revealed that joints that had been rejected for failing to fully fill the plated-thru hole lasted significantly longer than filled holes. No effort had been made to control the amount of solder in the hole, but the data clearly indicated that the less the amount of solder in the plated-thru hole, the longer the termination survived thermal cycling, as long as no other anomalies were

evident. In order to confirm this premise, a test board consisting of 560 35-mil-diameter plated-thru holes was constructed. The holes, with and without component leads, were wave soldered to yield various degrees of solder fill.

The board was subjected to 100 cycles of -50°F to +160°F (20 minutes at each extreme) without evidence of failure. This initial test demonstrated that the PTH termination, regardless of solder fill quantity, is capable of meeting typical storage life conditions (refer to Table 6).

Three-hundred and twelve of the joints were microsectioned as part of the examination during the first phase of the test. The remaining 248 joints were then destruct-tested to determine the effect that the degree of solder fill has on joint reliability. The destruct test consisted of 100 cycles of -85°F to 300°F (15 minutes are each extreme). Eighty joints were microsectioned and examined after 1, 50, and 100 cycles. After 1 cycle, no cracking was evident. After 50 cycles, micro cracks were evident in the plating of the PTH adjacent to the epoxy surface of the board. Visible solder metal fatique was evident. After 100 cycles, catastrophic failures occurred. The following is a summary of test results (refer to Table 7):

a. Completely Filled Plated-Thru Holes. These were the only joints acceptable to MIL-Spec requirements; 94% failed catastrophically.

b. Partially Filled Plated-Thru Holes. These terminations were between 25 and 50% filled with solder. PTH's with and without component leads were part of this sample; 92% failed catastrophically. The majority of failures occurred in PTH's containing component leads.

c. Unfilled Plated-Thru Holes. These holes were masked during wave soldering so that no solder was allowed to enter the hole. Only 12% of these holes failed catastrophically.

The following is a summary of the conclusions reached as a result of the above test program:

a. Cracks in the plated-thru hole or solder degradation as a result of thermal cycling will not occur on typical hardware programs (-50°F to +160°F), regardless of solder fill quantity. Therefore, there is no advantage to inspecting for these criteria on the component side of the board.

b. The destruct test that was performed (-85°F to +300°F) proved that unfilled plated-thru holes last considerably longer than filled holes. Therefore, there is no advantage to inspecting holes without component leads on either side of the board.

Table 7. Martin Marietta thermal shock cycling to destruct levels, test results

Quantity of Solder In Plated-Thru Hole	Sample Size	Number of Failures	% Failed
Full (Raised Fillets)	62	58	94
Partially Filled	124	114	92
Unfilled	62	8	12
Total	248	180	72

NOTE: All samples had been previously exposed to the testing of Table 6 and were selected from the 2238 acceptable joints.

SECTION VI

LEC SOLDER JOINT INSPECTION EXPERIENCE

Lockheed Electronics Company (LEC) has accumulated considerable experience on NASA and military Hi-Rel soldering programs. The Mk 86 Gun Fire Control System (Navy) and the LANCE Adaption Kit (Army) are two current programs that have seen solder joint inspection philosophies move in opposing directions. Adherence to cosmetic requirements has been relaxed on the Mk 86, while it has increased on the LANCE, since the beginning of each program. Early Mk 86 P.C. solder joints were inspected 100% at 4X magnification, no cosmetic defects were permitted and the solder fill in plated-thru holes had to be at least flush with the top side of the board. Inspection is now performed with the unaided eye. One pin hole (no larger than .010 inch diam) is permissible and fillets in plated-thru holes can be depleted on the top side of the board. These changes have resulted in a 50% - 60% improvement in productivity for Mk 86 P.C. solder joints.

LANCE solder joint inspection requirements were increased as a result of the incorporation of MIL-STD-1460(MU) in place of MIL-S-45743. The magnification for visual inspection was increased from 4X to 6X-10X. Fillets on the top side of the board were required to meet the same cosmetic requirements as bottom side fillets (zero imperfections). These changes have resulted in an 80% to 100% decrease in solder joint productivity. The increased magnification has resulted in a 30% to 50% increase in inspection time-per-joint due to eye strain. The inspection of both sides of the board has increased rework by approximately 50%.

A further comparison of these two programs is beneficial because both use the same wave soldering equipment to solder the P.C. boards. The inspectors are experienced on both programs and the same type of automated test equipment is utilized for both programs.

A COMPARISON OF SOLDER JOINT INSPECTION PERFORMANCE - MK 86 VS LANCE

It must be noted that the manufacturing sequence used on LANCE calls for 100% inspection of solder joints by Q.A. after hand touch-up by an operator, following wave soldering. Mk 86 boards are inspected on a random sample basis representing 6% of the boards in the run, but never less than one P.C. board after wave soldering and prior to touch-up.

Inspection of Mk 86 solder joints with the unaided eye vs 6X-10X magnification (as used on LANCE) results in a 50% to 60% decrease in soldering defects, principally in the area of pinholes. Discussions with the operator designated to perform the touch-up operation on LANCE boards prior to visual inspection indicate that 60% - 80% of the joints and the interconnecting circuit paths have to be touched up on each side of the board to meet LANCE cosmetic requirements. The majority of these defects are pinholes that can only be detected under 6X-10X magnification, and uneven solder flow on interconnecting circuit paths. The majority of the defects noted (and subsequently touched up) have no bearing on the solder joint bond reliability. Table 8 contains a comparison of Mk 86 and LANCE solder joint defect rates covering the January thru April 1976 production period.

Table 8. Comparison of Mk 86 vs LANCE solder joint visual inspection performance

	LANCE	MK 86
Soldering Specification Imposed	MIL-STD-1460	MIL-S-46844
Method of Inspection	100% Visual (Sample)	100%
Magnification Used During Inspection	6X - 10X	0
No. of Boards Inspected	212	140*
No. of Solder Joints Per Board	536	254 (avg)
No. of Solder Joints Inspected	113,632	35,503
No. of Cosmetic Defects Prior to Touch-Up	79,000**	50
No. of Cosmetic Defects After Touch-Up	5	N/A
% Cosmetically Defective at Q.A. Vis. Insp.	.0044%	.0141%

*Represents sample size for total of 2,063 boards.

**Estimated average no. of joints and streets requiring touch-up prior to Q.A. visual inspection based on operator experience (60% - 80%).

Table 8. Comparison of Mk 86 vs LANCE solder joint visual inspection performance (Cont)

	LANCE	MK86
Solder Defects by Category		
Dewetting	2	0
No Solder	1	13
Bridging	1	3
Pinholes	0	15
Solder Splash	1	0
Solder Peaks	0	19

A COMPARISON OF SOLDER JOINT TEST PERFORMANCE - MK 86 VS LANCE

The Quality Assurance Department at LEC reviewed production test records for both the LANCE and Mk 86 program. None of the test records indicated a reject attributable to a solder defect on either program. Q.A. also held discussions with LEC production test supervisors who confirmed that no electrical failures have been found due to a P.C. solder defect within the past four years on either program.

FIELD PERFORMANCE OF LEC SOLDER JOINTS

Since the LANCE missile is a standby weapon system, very little operational data is available. The functional (destruct) tests and flight tests that have been performed to date have not indicated any failures attributable to P.C. soldering defects.

The MK 86 production system has been operational for about six years, and each field failure is documented by the Navy and forwarded to LEC for review and corrective action as appropriate. A review of Mk 86 system performance for eleven systems, covering the period from 1 January 1974 thru 22 March 1976, reveals only nine failures attributable to defective solder joints. Of these only four were P.C. solder joints. This represents a failure rate of 0.0000069% per 1000 hours of Mk 86 P.C. solder joints (refer to Table 9). It should be noted that the Mk 86 solder joint inspection requirements are less stringent than LANCE, yet documented field performance data indicates a P.C. solder joint failure rate within the limits imposed on Minuteman P.C. assemblies (.00005 percent per 1000 hours).

Table 9. Computation of Mk 86 P.C. solder joint failure rate for the period Jan 1, 1974 through March 22, 1976

No. of Operational Systems	11
Avg No. of Boards Per System	3,683
Avg No. of Solder Joints Per Board	254
Avg No. of P.C. Solder Joints Per System: (3683) x (254) =	935,482
Total Accumulated Operational Hours	61,824
Accumulated Joint Hours = (935,482) x (61,824) =	57,835,239,168
No. of Defective P.C. Solder Joints	4
P.C. Solder Joint Failure Rate = $\frac{4}{(5.78352....)} \times 10^{-10}$ =	$\frac{.0000069\%}{1000 \text{ Hrs}}$

SECTION VII

INDUSTRY'S APPROACH FOR IMPROVING SOLDER JOINT RELIABILITY AND REDUCING VISUAL INSPECTION COSTS

All of the test programs cited in Section V had the common objective of determining which visual attributes of a solder joint were indicative of the reliability of the joint. The results of these studies indicate that, as long as there is evidence of wetting within at least 50% of the available bonding area, the reliability of the joint is assured. Industry is responding by concentrating on techniques that assure the wetting of solder, and produce functional, rather than "pretty," solder joints. By applying this principle, several commercial suppliers have already succeeded in eliminating as much as 80% of the visual inspection formerly required on completed P.C. solder joints.

Military suppliers such as "Martin" have matched these results on pilot test programs, and have accumulated over 12 billion joint hours without a solder joint failure. The approach being used to accomplish these impressive results is one of rigid process control. The following paragraphs describe the materials, processes and Quality Assurance controls that have been successfully applied on Hi-Rel commercial (and to some extent, military) programs.

PROCESS CONTROL OBJECTIVES

The soldering of printed circuit boards is ideally suited to process control techniques. The key elements to be controlled in the soldering process are:

a. Solderability

b. Time

c. Temperature

d. Cleanliness

Technology has finally provided the equipment, the material, and the knowledge to control these parameters within extremely accurate limits. The objective of a controlled process for producing P.C. solder joints is to utilize this technology for the manufacturing of highly reliable solder connections, without subsequent rework or touch-up, and with a minimun of visual inspection after soldering.

THE ROLE OF QUALITY ASSURANCE IN CONTROLLING THE SOLDERING PROCESS

At present, the Q.A. role is primarily one of visually inspecting the materials to be soldered before and after the soldering operation. Whether or not a component lead or plated-thru holes will solder cannot be determined by looking at them. It has also been demonstrated that looking at the connection after soldering cannot determine whether or not the joint will survive storage and operating environments for the life of the program. It is possible, however, to assure end item reliability of solder joints by controlling the soldering parameters with a quantitative assessment of the process. In other words, Q.A. must determine joint quality before, rather than after, the joint has been soldered. The process must be controlled from the point of manufacturing of the raw P.C. board through the cleaning process after wave soldering. The following paragraphs describe the types of controls that are essential for guaranteeing solder joint reliability.

CONTROLLING P.C. BOARD RELIABILITY

Current quality acceptance procedures for P.C. boards are adequate for controlling most of the parameters that affect the reliability of the board itself. However, additional controls are needed to assure solderability and to guarantee the reliability of the plated-thru holes.

DETERMINING BOARD CLEANLINESS

During the manufacture cycle, a P.C. board is subjected to a number of chemicals. The resist material, the chemical etchant, copper and tin oxides, and residues from adhesives combine to form an undetermined number of compounds on the surface of the board. The user generally has no way of knowing whether or not these materials have been thoroughly removed from the board. The first indication of contamination is usually after wave soldering, and is evidenced by dewetting. The problem is predominant in the most critical areas of the board, such as the plated-thru holes, where contaminating residues are more difficult to remove. Recent equipment developments have now made it possible to predetermine board cleanliness by quantitative methods. Alpha Metals Inc., and KENCO Inc., both offer test equipment that determines board cleanliness by measuring the concentration of ionizable salts-per-surface-area of the board. This equipment is described in greater detail on page 48 of the report.

DETERMINING PLATED-THRU HOLE RELIABILITY

A major objective is to predetermine the reliability of plated-thru holes. At present, the quality of a PTH is usually based on a visual determination of a sample of cross sectioned PTH's under 50X-100X magnification. The inspector looks for irregularities in the texture and thickness of the plating, and micro cracks that may result in failure. In many cases, it's not certain whether the cracks were a result of poor manufacturing, or if they were created by the cross sectioning process.

More companies are adopting the philosophy that PTH's should be evaluated in terms of their ability to withstand actual program requirements. For example, at Martin Marietta in Orlando, Fla., the test coupon manufactured with each P.C. board contains a series circuit of PTH's alternately interconnected on the top and bottom side of the board. After the bond strength tests are performed on a separate portion of the coupon, a test is performed to simulate actual thermal conditions that the board will be required to withstand during the life of the equipment (Ref b). The coupon is first immersed in oil at 500°F for 20 seconds to simulate exposure to wave soldering temperatures. The test pattern is then connected to an automatic continuity monitoring circuit with a chart readout. The coupons are thermal shock-cycled between the worse case (usually storage) hardware temperature extremes for the 100 cycles. The test can be performed unattended and the results give a realistic evaluation of the reliability of the PTH's.

This type of acceptance testing places the burden of assuring PTH reliability on the board supplier, where it belongs. It also helps to build a case for the eventual elimination of "C" wires or solder plugs as a spec requirement.

CONTROLLING SOLDERABILITY

If the soldering process is to be truly controlled, the system must be capable of making specific determinations of the compatibility of all the materials and processes involved. Solderability testing is the method used for making these determinations and, as such, is the major element of the control process. Virtually every other parameter of the component and P.C. board is specified in quantitative terms; yet, the most critical parameter necessary for achieving a reliable solder connection (solderability) is typically unspecified.

SOLDERABILITY TEST REQUIREMENTS

In the past, several attempts have been made to include a standard solderability test in purchasing specifications for components. MIL-STD-202 includes such a test and, while it may be of some value in controlling the component vendors plating process, it is of no value to the user by the time the actual soldering operation is performed. It will be shown later in this report that, compared to other methods for measuring solderability, the MIL-STD-202 dip test is the least effective. Other types of solderability tests, such as area of spread or capillary rise, can't be used on actual components in many cases, because of their configuration. Another drawback is that the results are dependent on a visual interpretation which is contrary to the objectives of this study. In order to be useful as a control technique, the solderability test must, therefore, be free of subjective visual interpretation, and should also include the following: (Ref 24)

a. The test method should use molten solder at the same temperature as the solder to be used during wave soldering.

b. It should be capable of measuring the actual quality of wetting achieved, instead of a "GO" - "NO GO" type of test that is based on an arbritrarily defined minimum limit. This requirement is essential because it permits the Q.A. inspector to determine the trend in quality before it reaches the lower limit, and avoids unnecessary halts in production, until the problem is resolved. It is also important for Q.A. to be able to predict the solderability of a large batch of components based upon the testing of a relatively small sample. Since the solderability of a large batch of components will show a distribution about a mean, the Q.A. engineer must be able to statistically predict the number of components that are likely to be unsatisfactory from measurements of samples which may, themselves, fall within satisfactory limits. The test method must, therefore, be capable of indicating subtle differences in satisfactory components.

c. It should be capable of monitoring the kinetics of the wetting process. Not only is the quality of wetting important, the time required to achieve wetting must also be determined. This is an essential point, because in a wave soldering operation the component lead (or PTH) will only be in contact with the wave for a fixed period of time. The Q.A. engineer must be satisfied in advance that full wetting will occur within that time period.

d. It must be capable of producing quantitative results. This is essential not only for determining quality trands, but it is absolutely necessary for the comparative testing of materials, and optimizing wave soldering line feed rates.

e. It must be suitable for a production type of operation. All of the current solderability tests are designed for a laboratory operation. To be useful as a process control technique, the test must be capable of being performed quickly on actual production hardware, at any stage in the production cycle, prior to wave soldering.

THE MENISCOGRAPH METHOD OF MEASURING SOLDERABILITY (Ref 33)

Up until 1971 there was no solderability test methods that could fully meet any one of the above test requirements. For this reason, a controlled process technique for soldering had never been possible. The Meniscograph was developed independently by General Electric in England, and by Philips in the Netherlands, specifically to satisfy these requirements.

The Meniscograph operates on the proven principle of surface tension in liquids. The instrument provides a continuous record of the wetting process by measuring the forces acting on a test sample partially immersed in molten solder. Until wetting begins, the solder will form a negative (downward) meniscus around the solder, resulting in an upward force on the sample equal to the weight of the solder displaced by the sample and the meniscus. When wetting begins, the solder moves upward, eventually forming a positive meniscus, resulting in a net downward force on the sample. The forces are measured as a function of time and are printed on a chart. The resulting curve reflects a direct correlation with the change in dihedral angle of the solder during the wetting process.

The Meniscograph can be used to measure solderability on P.C. laminates, component leads, terminals, wire, or any configuration which can be suspended vertically above a solder bath. The principle of operation, along with a typical solderability test curve, is illustrated in Figure 5.

THE ADVANTAGES OF THE MENISCOGRAPH OVER EXISTING SOLDERABILITY TEST METHODS

Previous solderability test methods were only capable of providing an indication of wetting. They failed to provide an adequate measurement of the quality or time of wetting. The MIL-STD-202 "Dip Test" does provide a reasonable simulation of the wave soldering process, but it is incapable of resolving differences in quality above a certain level. A major drawback is its dependence on subjective visual interpretation.

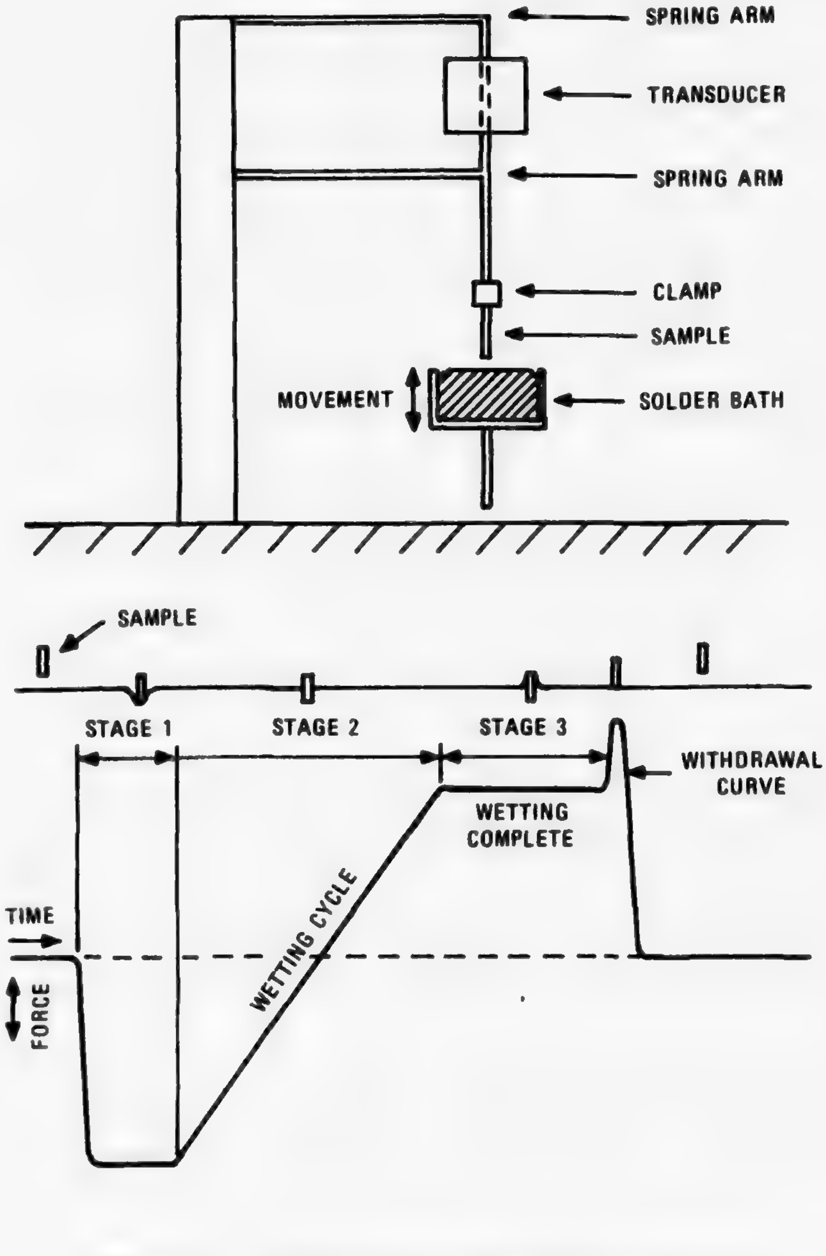


Figure 5. Operation of the "Meniscograph" and typical solderability test chart

In Europe, the globule test has become the standard solderability test. This consists of lowering a wire of the material and plating to be evaluated into a spherical bead of molten solder, and measuring the time for the bead to close around the wire. High speed movie film is generally used to interpret the results and to provide an indication of time. The significance of the test is questionable, however, because no measure is made of the quality of wetting and, by restricting the test to round wire configurations, P.C. laminates and some component leads cannot be evaluated. Although the test can be performed quickly, one must wait for film developing before the results can be interpreted.

The Meniscograph has the advantage of being able to perform tests on any sample configuration. The test is performed quickly and the results are immediate. The quality of wetting is determined by the measurement of the actual wetting forces plotted on the vertical axis of the recording chart, and the time to complete wetting is indicated on the horizontal axis of the chart. The chart serves as a permanent test record that is completely free of subjective interpretation.

THE USE OF THE MENISCOGRAPH AS A PROCESS CONTROL TOOL

The importance of solderability testing in the controlled processing of solder joints cannot be understated. Without a suitable method for evaluating solderability, statements such as "The quality and reliability of a connection must be predetermined before soldering" are of no value. Until the invention of the Meniscograph, there was no test method that could be applied to actual production hardware. There was no method other than visual inspection that could be used to determine the quality level of the soldering operation. The following paragraphs are intended to describe how the Meniscograph can be utilized on a production program to assure the quality and reliability of soldered connections.

The Design Phase - Selecting and Specifying Materials, Parts and Processes

The Meniscograph can be utilized during the design phase for the selection and evaluation of plating materials, plating thicknesses, presoldering cleaning solvents, solder alloys and fluxes. It enables the manufacturing engineer and the designer to perform quantitative, comparative testing, and thereby specify those materials that will provide optimum results. In the past, these decisions have been based on engineering judgement, advertiser's claims or expensive environmental testing of complete assemblies. In many cases, several changes are required during the early production phase, until the results of trial and error prove satisfactory.

Engineering judgement sometimes tends to result in an unnecessary margin of safety that could substantially affect the cost of the finished product. For example, at Martin Marietta, Orlando Div., only the highest purity solder alloy was used in the wave soldering operation. Although the solder used exceeded QQ-S-571* requirements, comparative testing on the Meniscograph revealed that several of the lower purity level solders (still in comformance with QQ-S-571) exhibited consistently better wetting action. In this case, reliability was increased and cost decreased as a result of quantitative solderability testing (Ref b).

Solderability testing of this type enables Quality Assurance to establish solderability distribution curves, as well as minimum acceptable levels of solderability, for all components to be soldered. These requirements can then be used in a variety of ways to assure the desired quality level of the soldering program. Figures 6 through 19 depict typical Meniscograph test charts for a variety of material and process evaluations. These figures demonstrate the utility of the Meniscograph for making Engineering and Quality Assurance decisions.

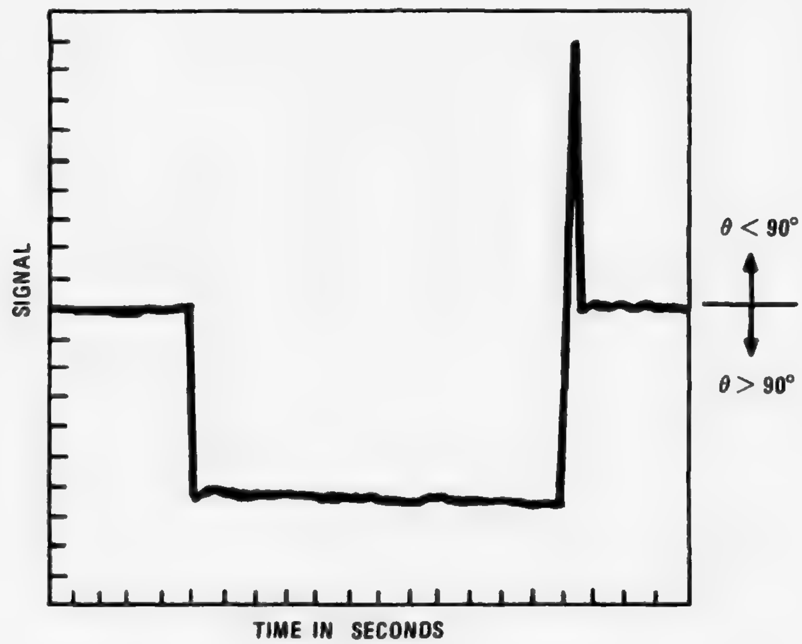
Controlling the Solderability of Component Parts

The solderability test performed during the part selection phase of a program can be translated into specific procurement acceptance test requirements and specified on the procurement drawing for the part. Solderability tests can be performed on a sample basis during incoming inspection, and can be used as a basis for accepting or rejecting the parts. In the past, component suppliers have seldom been challenged regarding the quality of their plating or cleaning processes. The Meniscograph enables the user to perform this evaluation in a quick and cost-effective manner. Component part distributors will find some difficulty in meeting solderability test requirements for parts that have been "on the shelf" for long periods of time. The resolution of such problems by the component suppliers will further upgrade the reliability of the finished product.

Controlling the Effects of Storage on Component Solderability

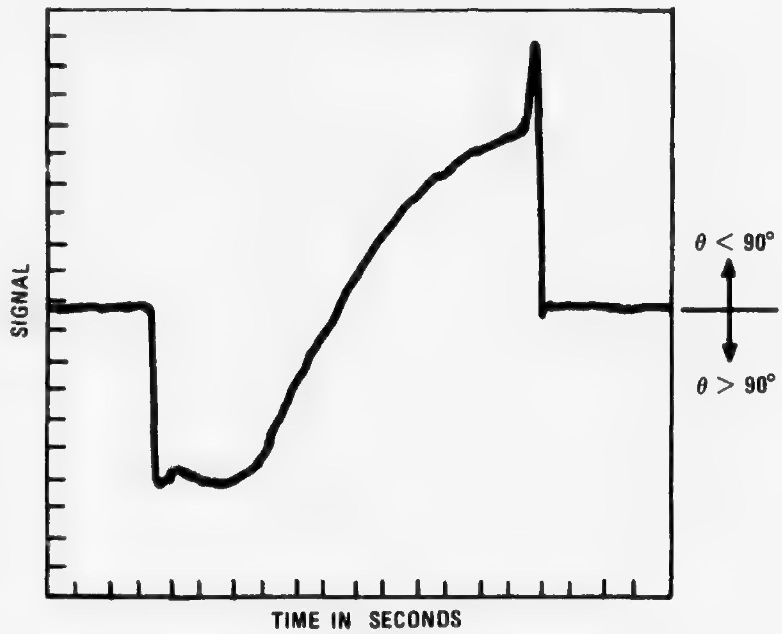
In most cases, components are ordered in large quantities in order to take advantage of lower piece part cost rates. As a result, some components may be stored in stock for up to a year before they reach their designated assembly. Unless the storage atmosphere is specifically controlled, contaminants found in the ambient air can be absorbed by the component plating, resulting in a surface that will not wet (see Figure 16). Components should, therefore, be solderability tested on a sample basis as soon as they are drawn from stock. The test results can be used to determine whether or not vendor packaging, ambient atmosphere or stock handling has any degrading effect on component solderability.

*QQ-S-571 is the accepted industry standard for tin-lead solder alloys.



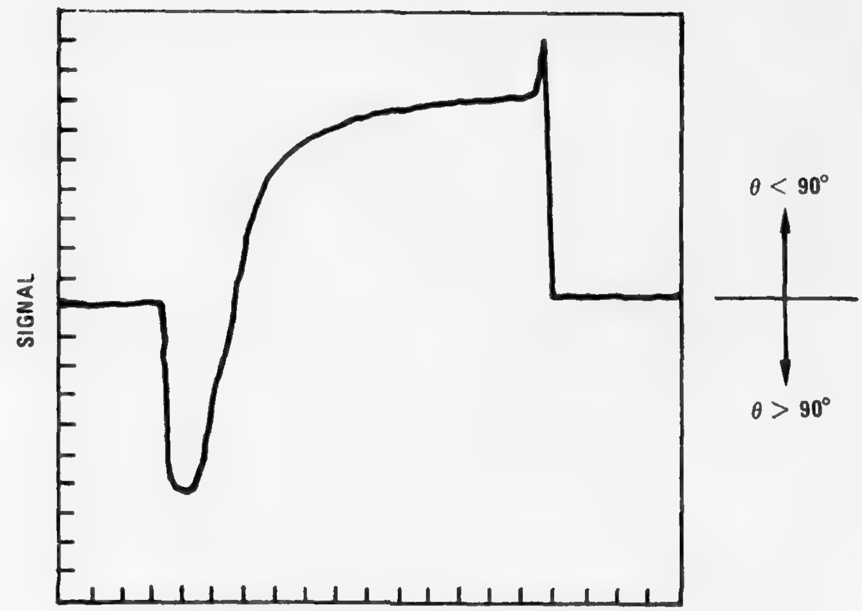
NOTE: THE CURVE SHOWS THAT EVEN AFTER 12 SECONDS WETTING HAD NOT BEGUN.

Figure 6. Meniscograph of naturally aged copper, no flux



NOTE: THE CHART SHOWS THAT USING AN UNACTIVATED FLUX, IT TAKES APPROXIMATELY 3 SECONDS TO BREAK DOWN THE OXIDE LAYER AND MORE THAN 12 SECONDS TO ACHIEVE FULL WETTING.

Figure 7. Meniscograph of naturally aged copper using a pure rosin in alcohol (unactivated) flux

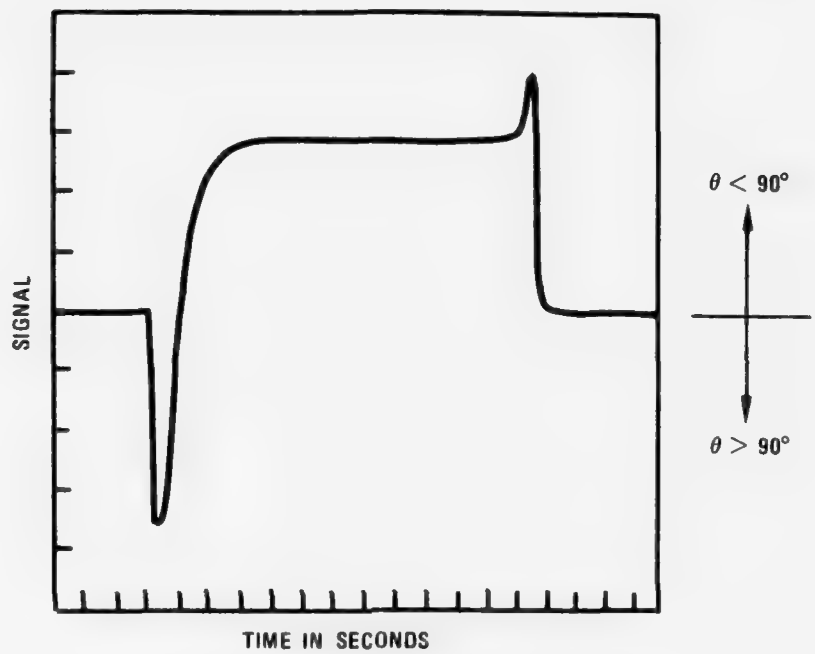


NOTE. THE CHART SHOWS THE IMPROVEMENT IN WETTING BY THE SLIGHT ADDITION OF AN ACTIVATOR. WETTING BEGINS IN ABOUT 1 SECOND AND WOULD APPEAR COMPLETED IN ABOUT 4 SECONDS BY OTHER TEST METHODS' HOWEVER, THE MENISCOGRAPH REVEALS THE PROCESS DOES NOT REACH EQUILIBRIUM UNTIL AFTER 9 SECONDS OF IMMERSION IN THE SOLDER BATH.

Figure 8. Meniscograph of naturally aged copper, slightly activated (0.05% Halide) rosin in alcohol flux

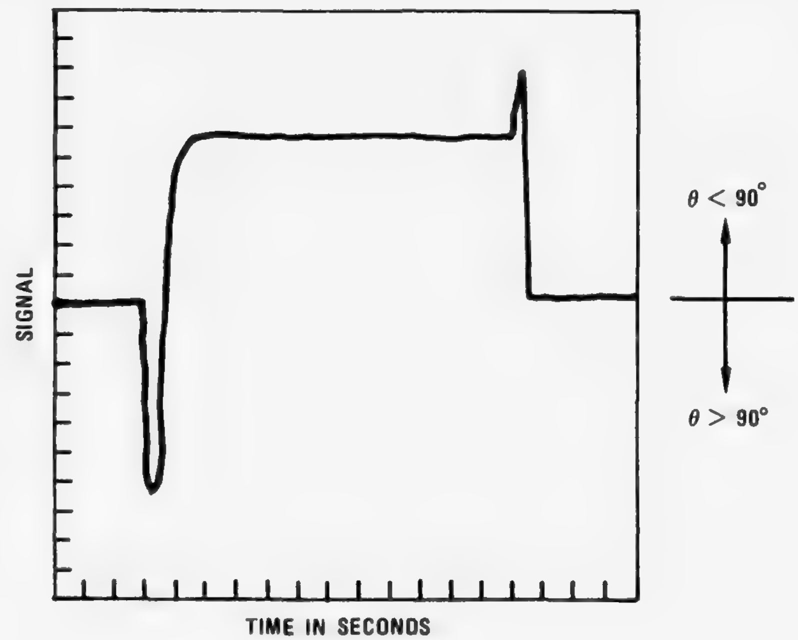
NOTE: THE CHART SHOWS THAT WETTING BEGINS AFTER ABOUT 0.4 SECOND AND WOULD APPEAR COMPLETED IN 3 TO 4 SECONDS BY OTHER TEST METHODS. THE WETTING ACTION HAD NOT REACHED EQUILIBRIUM WITHIN THE 12 SECOND PERIOD INDICATING THE POTENTIAL FOR EVEN GREATER WETTING IF BETTER FLUXING COULD BE IMPLEMENTED.

Figure 9. Meniscograph of naturally aged copper, mildly activated (RMA) (0.5% Halide) rosin in alcohol flux



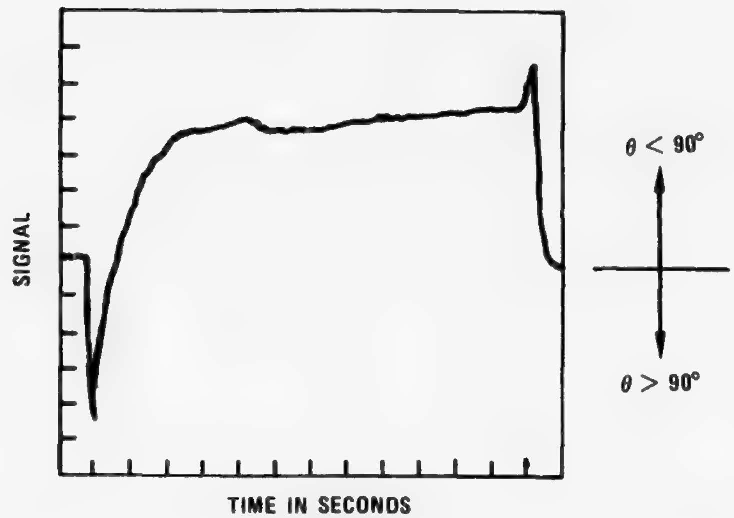
NOTE: THE CHART CLEARLY SHOWS THE TREMENDOUS IMPROVEMENT IN WETTING ATTAINED WITH AN RA TYPE FLUX. WETTING BEGINS WITHIN 0.2 SECOND AND MAXIMUM WETTING IS ACHIEVED WITHIN 4 SECONDS.

Figure 10. Meniscograph of naturally aged copper, highly activated (RA) (1.0% Halide) rosin in alcohol flux



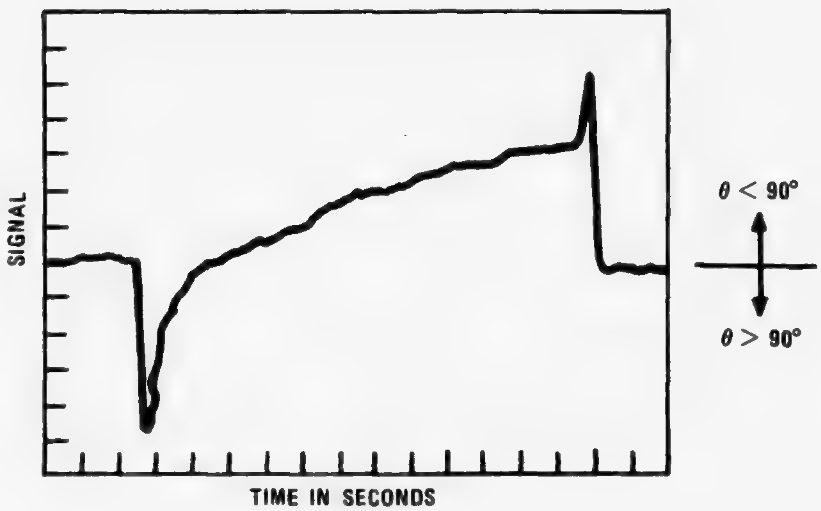
NOTE: THE CHART DEMONSTRATES THE PRODUCTIVITY IMPROVEMENTS THAT CAN BE ACHIEVED WITH FULLY ACTIVATED FLUXES. FULL WETTING (UNDER WORST CASE SURFACE CONDITIONS) IS ACHIEVED IN 2 SECONDS AS COMPARED TO 12 SECONDS USING AN RMA TYPE FLUX. THIS MEANS THAT LINE FEED RATES COULD BE INCREASED UP TO SIX TIMES THE PRESENT RATE WITHOUT AFFECTING SOLDERABILITY.

Figure 11. Meniscograph of naturally aged copper, water-soluble flux



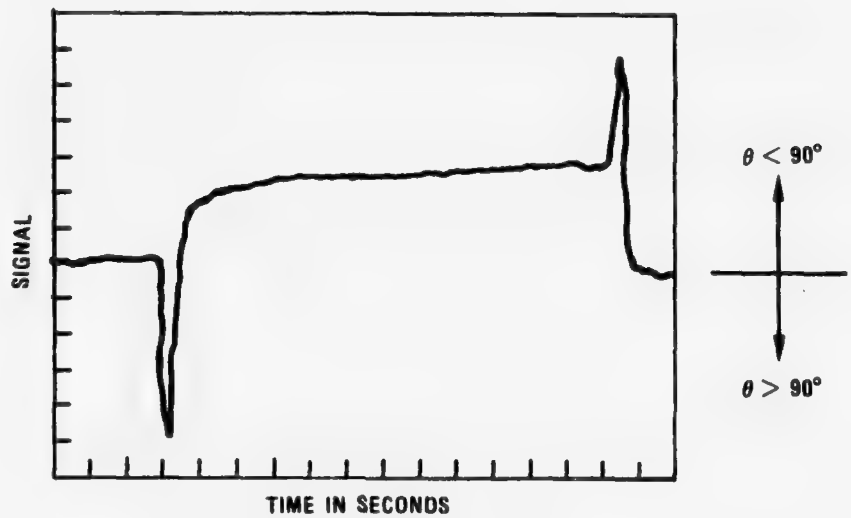
NOTE: THE CURVE SHOWS THAT GOLD BEGINS WETTING ALMOST INSTANTLY. THE ERRATIC BEHAVIOR OF THE CURVE BEYOND THE 90° DIHEDRAL ANGLE POINT REFLECTS THE FORMATION OF TIN-GOLD INTERMETALLICS WHICH WILL RESULT IN EMBRITTLED JOINTS.

Figure 12. Meniscograph of gold (1 um) over copper, surface cleaned prior to testing



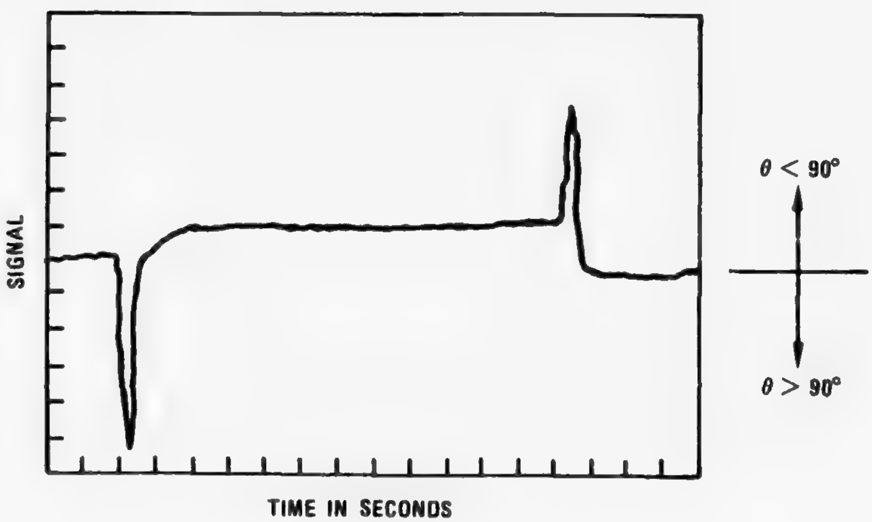
NOTE: THE CHART SHOWS THAT IN THE EARLY STAGES OF WETTING THERE IS LITTLE DIFFERENCE BETWEEN THE CLEAN (FIG. 12) AND DIRTY SURFACE BUT THAT THE DIFFERENCES ARE SIGNIFICANT BEYOND THE θ = 90° POINT. THIS TYPE OF TEST DATA IS USEFUL FOR EVALUATING CLEANING SOLUTIONS THAT ARE USED IN THE PROCESS PRIOR TO SOLDERING.

Figure 13. Meniscograph of gold (1 um) over copper, dirty surface



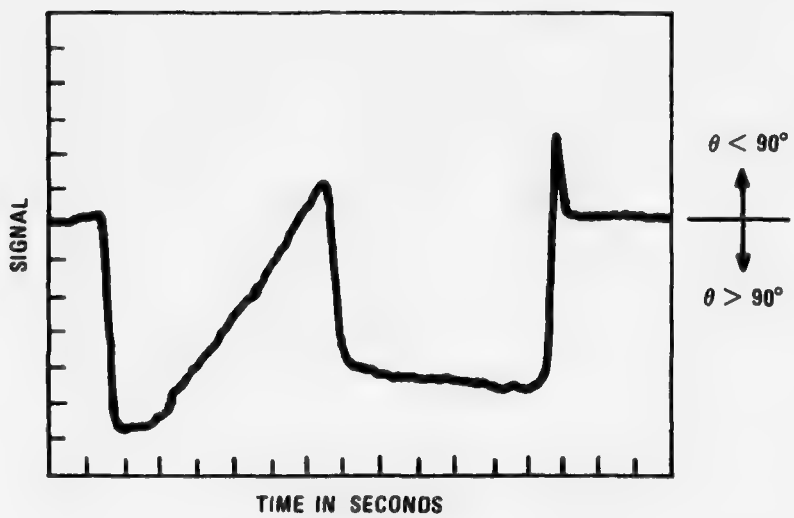
NOTE: THE CURVE SHOWS THAT WETTING REACHES STABILIZATION MORE QUICKLY WITH SILVER PLATING THAN WITH GOLD. (SEE FIG. 12). THE CURVE ALSO SHOWS THAT THE WETTING FORCES AND DIHEDRAL ANGLE (θ) ARE LOWER FOR SILVER THAN THEY ARE FOR GOLD AFTER 12 SECONDS.

Figure 14. Meniscograph of silver (1 um) over copper, surface cleaned



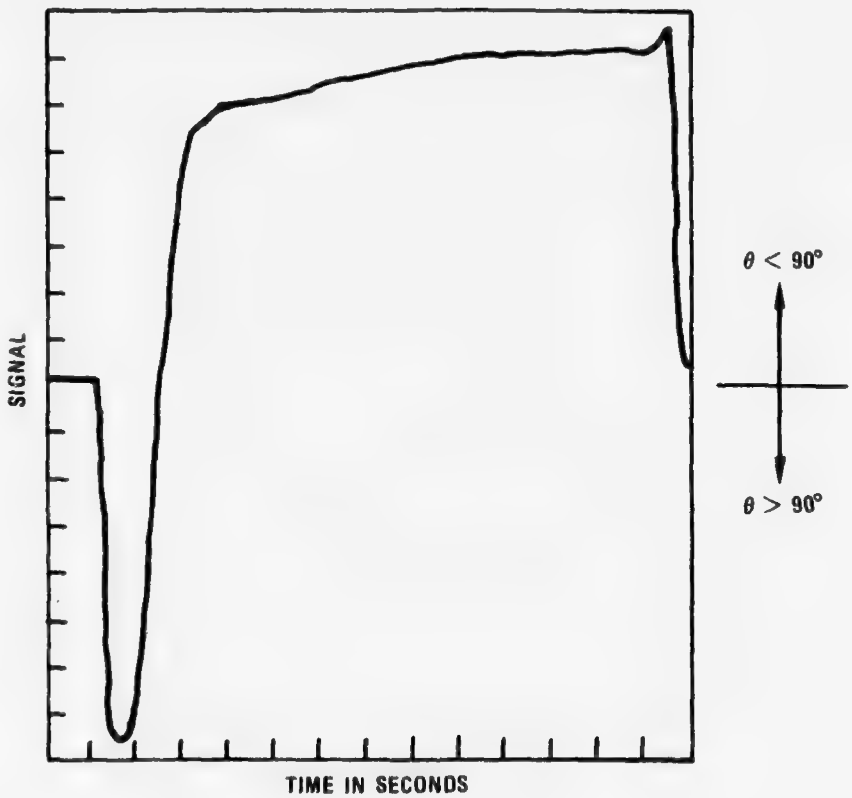
NOTE: CURVE SHOWS THAT INITIAL WETTING IS RAPID BUT STABILIZATION LEVEL IS EXTREMELY LOW.

Figure 15. Meniscograph of silver (1 um) over copper, dirty surface



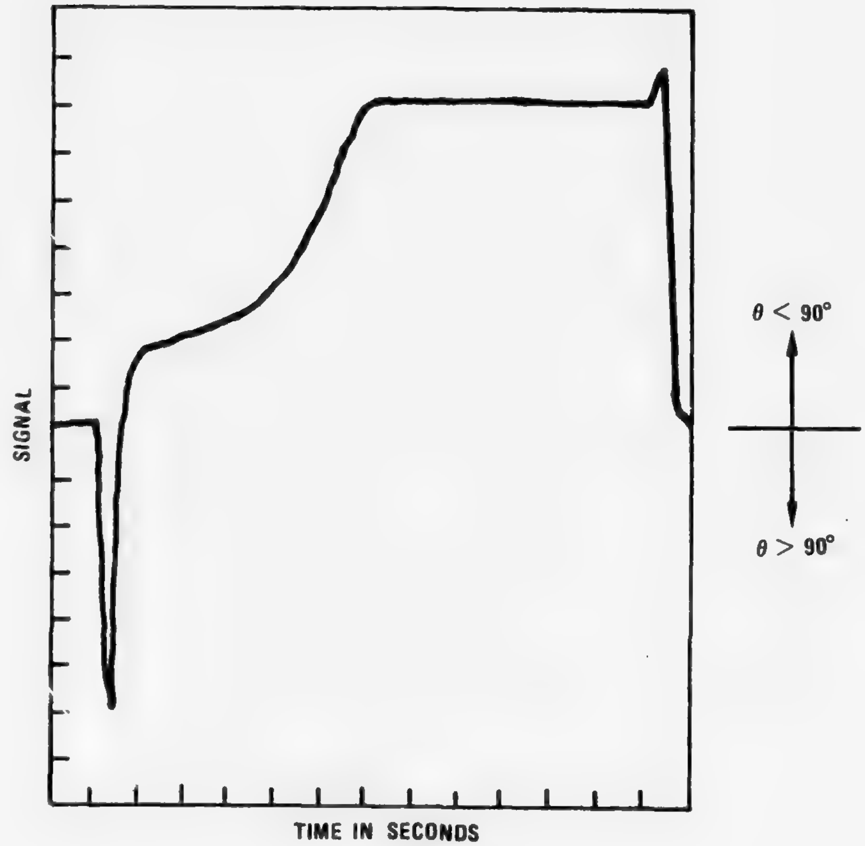
NOTE: THE CURVE SHOWS HOW THE MENISCOGRAPH CAN BE USED TO ANALYZE THE EFFECTS OF KNOWN AND UNKNOWN CONTAMINANTS ON SOLDERABILITY. WETTING IS NORMAL INITIALLY, HOWEVER ONCE THE TIN-LEAD PLATING IS DIFFUSED, THE SULFUR REACTS WITH THE COPPER TO FORM AN INSULATING LAYER THAT WILL NOT WET. THIS TYPE OF ANLAYSIS IS USEFUL IN EVALUATING THE SOLDERABILITY OF BOARDS AND COMPONENTS THAT HAVE BEEN STORED IN PLASTIC BAGS OR IN OTHERWISE POTENTIALLY DAMAGING ENVIRONMENTS.

Figure 16. Meniscograph of tin-lead (1 um) over copper with sulfide contaminate on surface



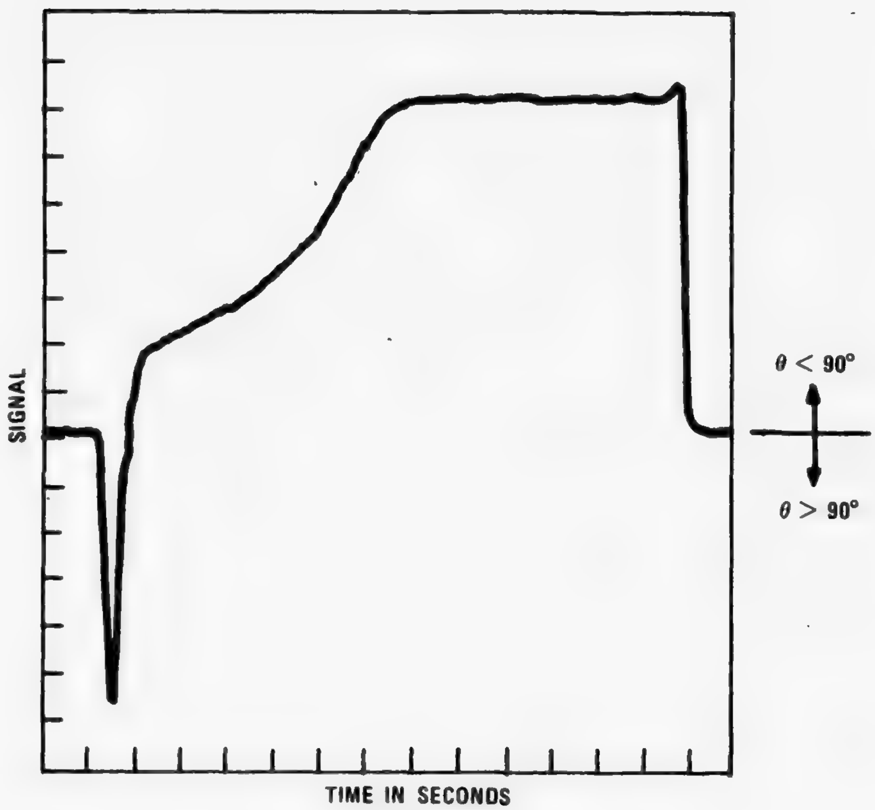
NOTE: THE FOLLOWING SEQUENCE OF FIGURES SHOWS HOW THE MENISCOGRAPH CAN BE USED TO EVALUATE A PRODUCTION PROCESS. THE PROCESS ANALYZED IS THE SOLDER MELTING METHOD FOR REMOVING GOLD IN ORDER TO ELIMINATE REJECTS FOR EMBRITTLED JOINTS. THE CHART SHOWS THAT AFTER 12 SECONDS WETTING WAS NORMAL FOR GOLD PLATED SURFACES.

Figure 17. Meniscograph of gold (8 um) on copper, first immersion



NOTE: CHANGE IN WAVESHAPE INDICATES A CHANGE IN THE SURFACE CHEMISTRY. IT IS CLEAR THAT THE SURFACE BEING WETTED IS NOT FULLY SCAVENGED OF GOLD SINCE THE CURVE FOR UNPLATED COPPER WOULD BE SIMILAR TO FIGURE 17 IN GENERAL SHAPE.

Figure 18. Meniscograph of gold (8 um) on copper, second immersion



NOTE: CURVE SHOWS THAT SURFACE CHANGE IS PERMANENT AND WILL NOT BE AFFECTED BY REPEATED IMMERSIONS. THE CURVE INDICATES THE FORMATION OF A GOLD-TIN-LEAD (TERNARY) ALLOY AFTER THE FIRST IMMERSION. THIS ALLOY HAS A MELTING TEMPERATURE HIGHER THAN SOLDER. THE TEST DEMONSTRATES THAT SOLDER MELTING OF GOLD IS UNEFFECTIVE FOR REMOVING ALL OF THE GOLD FROM THE SURFACE.

Figure 19. Meniscograph of gold (8 um) on copper, third immersion

Controlling Solderability During the Manufacturing Process

Once components have been accepted from stock by Q. A., they will generally undergo several preassembly operations before wave soldering. This may include lead cutting and forming, pretinning, component insertion, etc. These operations may occur in different locations of the plant, and the parts may be handled several times prior to soldering. The Meniscograph can be used to perform periodic checks at any stage in the assembly cycle to assure that the process controls that have been imposed are adequate to retain solderability, and that the quality level of the assembly operation is within acceptable limits.

IMPROVING P.C. SOLDER JOINT RELIABILITY AND PRODUCTIVITY

It was indicated earlier in the report that wetting should be the primary concern for determining solder joint reliability. The test programs discussed in Section V revealed that the majority of surface imperfections for which solder joints are currently rejected have no bearing on the reliability of the solder joint. These findings have had an impact on recent developments in wave soldering equipment. In the past, equipment suppliers were dedicated to developing soldering systems that yielded cosmetically perfect solder joints. In many cases, these requirements restricted the use of techniques that would promote better wetting. One such example is the use of tinning oil in the solder wave. The advantages of tinning oil have been known for years; however, the controversy surrounding its use has led many contractors to abandon it on military programs. The problem stems from the mistaken notion that the intermixing of oil in the solder wave is akin to willfully introducing contaminants into the solder joint. This was evidenced by the fact that joints soldered with oil often exhibit tiny voids caused by entrapped oil. The surface of these joints may also appear porous as a result of the impressions formed by particles of oil during cooling. Now that test results have indicated that porous joints outlast "perfect" joints, as long as there is equal wetting, the use of oil is being reintroduced at many facilities.

THE ADVANTAGE OF OIL DURING WAVE SOLDERING

There are two significant advantages to use tinning oil during wave soldering: Improved wetting, and improved productivity.

Improving the Wetting Characteristics of Solder

Wetting is improved because the oil acts in two ways to increase the bonding area. Initially, the oil acts as a lubricant that allows the solder to spread over a larger area before chemical bonding even begins. The oil also contains additives which enhance wetting. The additives are chain-like molecules having a polar group on one end and a string of carbon atoms on the other. The polar end is naturally attracted to the conductor surface by Van Der Waals forces.* This attraction upsets the molecular equilibrium of the additive, causing its carbon chain to break up and be dissolved by the oil. These attractive forces act in opposition to the surface tension forces of the solder, thereby allowing the solder to spread over (wet) a greater area (Ref 26).

This type of wetting action is independent of the flux, and continues to promote wetting even after fluxing activity has been completed. In most wave soldering operations, the boards are pre-fluxed and a significant amount of the flux is washed away by the solder wave before the wetting agents have accomplished their function. The additives in the oil offset this deficiency, because they are present and active throughout the entire soldering process.

The improved wetting achievable with oil has been demonstrated by Meniscograph tests (see page 57) on chemically cleaned copper without flux. Without the presence of oil, the solderability curve was similar to that shown in Figure 7. When the same test was performed using an intermix of oil in the solder, the resulting curve was similar to that of Figure 8. These findings have encouraged further development of oil intermix systems, and several types are now being employed on military programs. The major area of improvement has been in the design of the pumps. New designs permit the controlled injection of micro-particles of oil within the solder. The resulting joints are significantly less porous in appearance and will withstand current cosmetic inspection criteria, if performed without magnification.

How Tinning Oil Improves Solder Joint Reliability

Testing has demonstrated that joints soldered with tinning oil are considerably stronger (see page 80). When molten solder reacts with copper, a chemically distinct intermetallic compound ($Cu_6 Sn_5$) is formed at the interface. The longer that molten solder is in contact with the copper, the thicker the intermetallic layer becomes. The intermetallic compound is extremely brittle compared to either the copper or the solder; therefore, it is in the best interest of joint reliability to keep the thickness of the intermetallic layer to a minimum (Ref 27). This can be accomplished by minimizing the time and

*Cohesive and adhesive forces between molecules.

temperature for soldering. The improved wetting that is achieved when oil is intermixed with the solder permits soldering at temperatures many degrees lower than without oil. The reduction in friction and surface tension forces permits soldering time to be reduced, thus assuring a thin intermetallic layer.

How Tinning Oil Improves Solder Joint Productivity

Oil improves solder joint productivity by reducing cost and soldering time. Cost is reduced because less solder is consumed per joint, and less solder is wasted in the formation of dross. Time is reduced because oil retards formation of icicles which have been the major factor in limiting line feed rates for wave soldering. For joints without oil, there is a tendency for solder quantity to be excessive. This is due to the high surface tension forces of liquid solder. These forces tend to pull additional quantities of solder from the wave just as the joint is leaving the wave area. As explained on page 76, the oil tends to minimize these surface tension forces and thereby discourage unneeded solder from being drawn from the wave.

Once the unused solder returns to the reservoir, the oil rises to the surface of the solder, where it acts like a barrier that retards the formation of dross. This aspect of the oil intermix system results in significant savings, even on moderate production rate programs.

Productivity is significantly improved by the elimination of unnecessary rework. A prime example is the previously mentioned area of excessive solder. A significant number of otherwise acceptable joints are rejected because the inspector cannot distinguish the component lead. As a result, an operator is required to "wick" off the excessive solder and resolder the joint manually. The use of oil virtually eliminates this condition, and thereby contributes significantly to improved productivity.

Line feed rates can be increased with an oil intermix system because of the reduced back-wash area between the board and the trailing edge of the wave (see Figure 20). The backwash area is formed by both the vacuum created between the exiting board and the wave, and the high surface tension forces of the solder. High speed films have shown that the surface tension forces predominate, because when oil is injected into the wave, the backwash area is visibly reduced. Reducing the backwash area is significant from a production viewpoint because it drastically reduces the incidence of icicles and solder bridges. The margin of improvement is so dramatic that the line feed rate can be increased by 50 to 100% without creating solder bridges.

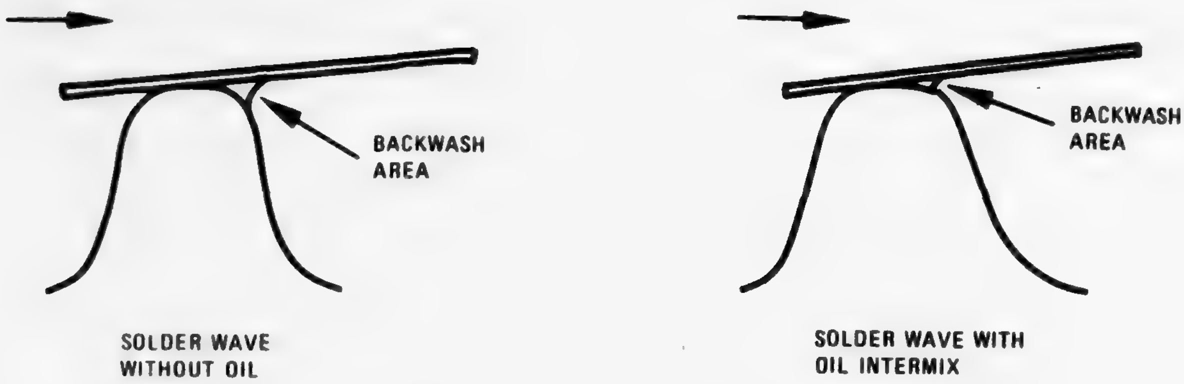


Figure 20. The effect of oil on solder wave backwash area

Evaluation Tests Performed on the Oil-Intermix Wave-Soldering System

As a result of their studies indicating the insignificance of pinholes and voids (see Section V) in solder joints, Martin Marietta, Orlando Div., was among the first to re-evaluate oil-intermix soldering systems. In the early part of 1972 a test program was developed by Martin to compare solder joints prepared with and without the use of tinning oil (Ref 25). Quantities of identical boards were soldered on the oil-intermix system, and on Martin's normal (non-oil) production wave soldering equipment. Since the results achievable on the normal production equipment were well known to Martin personnel, fewer boards (118) were tested on that system. 342 boards were soldered on the oil-intermix (O.I.) system. After soldering, the boards were visually inspected for the following defects:

a. MAJOR - Skips

Icicles

Excessive solder

Bridging

Dewetting

b. MINOR - Pin Holes

The O.I. soldered boards had 816 defects out of a total of 28,520 connections (2.8%) and 128 of the boards had no defects at all. The boards soldered on the normal production equipment had 2,612 defects out of 11,805 total connections (22%) and there were no boards that had zero defects (refer to Table 10).

Table 10. Comparison of joints soldered with and without the use of tinning oil (Ref 25)

	Wave Soldering Machine	
	Unit 1 (Intermix)	Unit 2 (Without Oil)
P/C Boards	342	118
No. of Connections	28,520	11,805
Defects	816	2,612
No. of Boards with No Defects	128	0
Percent Rework	2.8	22
Other Appearance Items	8/bd.	0.8/bd.
DEFECTS BY CATEGORY:		
MAJOR - Skips	1%	4%
Icicle	0%	2%
Excessive Solder	1%	5%
Bridging	0%	7%
Dewetting	2%	19%
MINOR - Pin Holes	5%	0%

Nineteen percent of the production system soldering defects were classified as dewetting. However, it should be noted that this category included uneven solder flow-a visible line of demarcation-as well as actual dewetting. The majority of these defects were actually uneven solder flow on circuit streets, a problem that is purely cosmetic but, nevertheless, rejectable to MIL-Spec soldering criteria. In this respect the reduction of this type of defect to 2% actually improved the cosmetic appearance of the board. As was expected the only area where the O.I. system resulted in an increase in defect rate was for pinholes.

Although depressed fillets were not included as a defect for the purposes of this test, most of the O.I. soldered joints had such fillets on the top side of the board. These joints were rejectable to MIL-Spec criteria; however, pull tests demonstrated that these joints were actually stronger than the raised fillet joints produced on the normal production soldering system. This agrees with previous tests that indicate that the quality of wetting is more important than quantity of solder for assuring solder joint strength (see Table 11).

Additional testing was performed on the O.I. soldered boards in order to determine if any oil had been absorbed by the joint and board material, that would subsequently bleed out and contaminate the conformal coating operation. After the normal cleaning operation, the boards were analyzed using ultrasonic cleaning techniques, vacuum testing to 10^{-3} mm Hg and black-lite inspection. *No oil bleeding was detected on any of the boards soldered on the O.I. system.*

NEW DEVELOPMENTS FOR IMPROVING P.C. ASSEMBLY PRODUCTIVITY

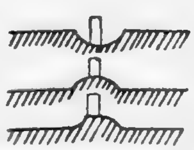
Hollis Engineering Inc., has recently introduced equipment that is an improvement on the fluxing and lead cutting techniques being used by the Japanese. (Refer to Section V.) The Japanese have had great success using activated and water-soluble flux; inserting components with full leads; dip soldering followed by automatic lead cutting; and then wave reflow soldering. The disadvantage with this approach is that the board and its components must be subjected to the 500°F soldering temperature twice per assembly. This is counterproductive to the reliability of plated-thru holes and to some temperature-sensitive components. Whether the long leads are first dip soldered, or soldered by deep wave machines, considerably more solder and flux are consumed in the operation. Also, deep wave machines form significantly greater quantities of wasteful dross than conventional machines.

The approach developed by Hollis eliminates the two-step soldering operation, and thus improves reliability by subjecting components and P.C. plated-thru holes to the 500°F soldering temperature only once per assembly. The approach is known as the Stabilizer Process, and utilizes a refined petroleum

Table 11. The effect of solder fill on the strength of plated-thru hole solder terminations (Ref 25)
Full Test Data

	Unit 1 - (Intermix)				Unit 2 - (No Oil)		
	Gold		Tin		Gold		Tin
Pin No.	Profile	Pounds	Profile	Pounds	Pounds	Profile	Pounds
1	1	22.0	2	21.3	11.7	3	-
2	2	19.2	3	25.0	12.8*	3	16.0
3	3	20.5	1	17.4*	16.2	3	14.8
4	1	15.6	1	19.7	17.1	3	15.8
5	2	17.5	1	18.8	17.3	3	17.1
6	2	20.7	2	25.6	18.7	3	16.3
7	1	16.5	3	23.0	14.8	3	15.7

*Pin Pulled Out



Pin Profiles	AVERAGE PULL STRENGTH			
	Unit 1 - (Intermix)		Unit 2 - (No oil)	
	Gold	Tin	Gold	Tin
#1 Depressed	18.03	18.63	N/A	N/A
#2 Flat	19.13	23.5	N/A	N/A
#3 Raised	20.5	24.0	15.51	15.95

Hole size = 0.035 in.

Pin size = 0.012 x 0.22 inch Kovar

wax to support long and short leaded components, so that leads can be automatically cut prior to wave soldering. The concept was further improved by adding flux activators to the wax, thus eliminating the need for separate prefluxing operation prior to soldering. The stabilizing process is conducted as follows: (Ref 28)

a. Boards with components hand-inserted, but with leads uncut, are packed and placed on a system conveyor.

b. The board passes over a 150°F pre-heater as it approaches a standing wave of molten wax.

c. The board then passes over the wax wave where all component leads and plated-thru holes are wetted by the wax. The temperature of the molten wax is no more than 170°F, which is about 300°F below soldering temperatures. The flux activators within the wax are also inert at this temperature and will not become active until soldering begins.

d. As the board leaves the wave, cooling fans solidify the wax, and the component leads are locked to the board.

e. Continuing on the same conveyor the board passes over high speed, carbide-tipped cutter blades, and all leads are trimmed to the same desired length in one pass.

f. The boards can then continue on the conveyor for wave soldering or be stored for soldering at a future date. The wax coating will preserve solderability during storage and handling.

Since the wax is a petroleum derivative, it is compatible with all the materials common to the P. C. assembly operation, including the latest tinning oils. Its melting point is about 155°F; however, best results are achieved at an operating temperature of about 170°F. Other important physical properties of the wax are shown in Table 12. During soldering, the wax helps to reduce surface tension in the same manner as the tinning oil (see page 76). Approximately 90% of the wax on the board is removed by the solder wave. The removed wax adds to the dross barrier formed by the tinning oil in the reservoir and, thus, further helps in the reduction of solder waste.

Table 12. Physical properties of petroleum wax used in stabilizer process (Ref 28)

Property	Typical Value	Test Method
Congealing Point	155°F/68°C	ASTM D938
Refractive Index at 80°C	1.437	ASTM D1218
Color, Saybolt (Melted)	+30	ASTM D156
Moisture, %	Nil	ASTM D95
Specific Gravity, 73°F/4°C	0.925	---
Specific Gravity, 180°F/4°C	0.785	---
Specific Gravity, 210°F/4°C	0.775	---
Lb/Gal., 180°F/82°C	6.55	---
Lb/Gal., 210°F/99°C	6.45	---
Flash Point, COC	500°F/260°C	ASTM D92
Spontaneous Ignition Temperature	825°F/440.5°C	---

The primary concern in evaluating this system was naturally in the area of cleaning. Testing has demonstrated that the wave (by itself) is inactive and does not contribute to ionic conductivity or surface volume resistivity. When used in combination with flux, the wax has no adverse effect on the cleaning procedure. (Refer to Tables 13, 14 and 15.) In fact, separate testing performed by Martin Marietta (Orlando) indicates that the wax facilitates cleaning by encapsulating ionizable salts produced by the flux activators (Ref b). It can be seen from the test results shown in Table 15 that, even when the same method was used for cleaning the boards after soldering, the boards soldered with any type of flux were generally cleaner (free of corrosive salts) when the wax was used during soldering.

Table 13. Surface resistivity of boards soldered with and without petroleum wax - after cleaning (Ref 28)

Flux	Surface Resistivity Test Results in Ohms[a]	
	Hot Water and Detergent Wash Plus Hot Water Rinse[b]	Cleaned with 1-1-1 Trichlorethane
RMA	1.52×10^{14}	7.41×10^{13}
RA	1.52×10^{14}	4.36×10^{13}
Water Soluble	1.09×10^{14}	2.40×10^{13}
Flux/Wax[c]	8.71×10^{13}	2.96×10^{13}
RMA and P.W.[d]	1.52×10^{14}	1.05×10^{13}
RA and P.W.	1.09×10^{14}	1.74×10^{14}
H_2O Sol. and P.W.	1.09×10^{14}	4.36×10^{8}

[a] Tests conducted per Mil-Std-202, Method 302 and ASTM D247: 500 VDC for one minute.
[b] Hot water rinse with plain tap water. Deionized water not used.
[c] Flux/wax is a mixture of petroleum wax and chemical activators.
[d] P.W. designates plain petroleum wax.

Table 14. Volume resistivity results of boards soldered with and without petroleum wax (Ref 28)

Flux	Volume Resistivity Test Results, in Ohm-Cm[a]	
	Hot Water and Detergent Wash Plus Hot Water Rinse[b]	Cleaned with 1-1-1 Trichlorethane
RMA	5.87×10^{13}	α
RA	α	α
Water Soluble	α	2.84×10^{14}
Flux/Wax[c]	α	α
RMA and P. W.[d]	1.98×10^{14}	2.21×10^{14}
RA and P. W.	2.43×10^{14}	α
H_2O and P. W.	α	α

[a] Tests conducted per Mil-Std-202, Method 302 and ASTM D257; 500 VDC for one minute.
[b] Hot water rinse with plain tap water. Deionized water not used.
[c] Flux/wax is a mixture of petroleum wax and chemical activators.
[d] P. W. designates plain petroleum wax.

Table 15. The effects of petroleum wax on board cleanliness (Ref 28)

Flux	Ionic Conductivity Test Results, in Microhms/Cm[a]			
	Hot Water and Detergent Wash Plus Hot Water Rinse[b]		Cleaned 1-1-1 Trichloroethane	
	100% Aqueous	Mil-P-28809	100% Aqueous	Mil-P-28809
RMA	0.27	0.20	0.23	0.05
RA	0.27	0.28	0.73	0.33
Water Soluble	0.23	0.15	18.72	6.20
Flux/Wax[c]	0.13	0.25	0.32	0.17
RMA and P.W.[d]	0.27	0.15	0.24	0.11
RA and P.W.	0.27	0.28	0.71	0.35
H_2O and P.W.	0.17	0.22	11.63	10.20

[a] Tests conducted using 100% aqueous solution and test procedure of Mil-P-28809. Both sets of obtained values are shown.
[b] Hot water rinse with plain tap water. Deionized water not used.
[c] Flux/wax is a mixture of petroleum wax and chemical activators.
[d] P.W. designates plain petroleum wax.

It should be noted that the cleaning solution must be heated above 155°F in order to dissolve the wax residue. This may appear as a drawback; however, experience has demonstrated that the efficiency of any cleaning operation is improved at elevated temperatures. Temperature control systems that comply with the OSHA regulations are readily available for this purpose.

The production benefits to be derived from the stabilizer process can be summarized as follows:

a. Hand trimming of component leads can be eliminated.

b. Hand clinching of leads, or methods for supporting components during soldering, is not required.

c. Boards can be assembled with missing components and stored for final assembly at a later date without losing solderability.

d. The wax helps to reduce surface tension during soldering, and further reduces the possibility of icicles and solder bridges.

e. The wax retards the formation of dross in the solder reservoir.

f. Significantly less flux activator is required per joint.

In addition to the production benefits, there are reliable advantages to be gained from the stabilizer process. Meniscograph tests performed on joints, soldered with wax containing flux activators (flux/wax), indicate that the net time to achieve wetting was lower than that achieved using water-soluble flux (refer to Table 16). This is due to the fact that, at soldering temperatures, the wax has the same effect as tinning oil for promoting wetting.

Table 16. The effect of petroleum wax containing flux activators on solderability (Ref 28)

Flux	Net Wetting Time, Seconds	Net Wetting Force, Grams	Net Wetting Rate, g/sec
RMA	--	--	--
RA	4.12	0.344	0.083
Water Soluble	3.03	0.45	0.149
Flux/Wax	2.68	0.389	0.145

Using wax as the transport for flux activators has other solderability advantages. Since the wax is applied by a standing wave very similar to the solder wave, the molten wax penetrates the same areas that will be wetted by the molten solder. When the flux is applied by spraying or foaming, the concentration of flux in the critical areas is uncertain. Activated wax can also improve the cosmetic appearance of solder joints by reducing the number of harmless pinholes. Since there is no boiling off of volatiles, such as there is when rosin and alcohol are used to transport the activator, pinholes resulting from boil-off are eliminated. Typical physical properties of activated flux are contained in Table 17.

Table 17. Typical properties of activated petroleum wax (Ref 28)

Property	Typical Value	Test Method
Congealing Point	150°F/66°C	ASTM D938
Refractive Index at 80°C	1.441	ASTM D1218
Color	6.0 Dilute	ASTM D1500
Viscosity at 210°F/99°C, cs	7.18	ASTM D445
Viscosity at 180°F/82°C, cs	9.98	ASTM D445
Specific Gravity, 73°F/4°C	0.935	---
Specific Gravity, 180°F/4°C	0.802	---
Specific Gravity, 210°F/4°C	0.791	---
Lb/Gal., 180°F/82°C	6.68	---
Lb/Gal., 210°F/99°C	6.59	---
Flash Point, COC	500°F/260°C	ASTM D92
Spontaneous Ignition Temperature	825°F/440.5°C	---

DETERMINING THE EFFECTS OF SOLDERING PROCESS ON P.C. BOARD CLEANLINESS

Without a nondestructive, quantitative production line test for demonstrating board cleanliness after soldering, many of the preceding technological advances could not be considered for military approval. In fact, without such a test, the entire prospect of accepting solder joints by controlling the soldering process could not be seriously entertained. A test method and a military specification on board cleanliness have recently been developed, however, to satisfy the above requirements. After extensive testing and evaluation to determine the level of surface contamination that will cause corrosive damage to P.C. assemblies, the Navy has released MIL-P-28809*, which establishes minimum acceptable limits for board cleanliness following soldering.

*MIL-P-28809 Military Specification for Printed Wiring Assemblies was approved for use by DOD agencies as of 21 March, 1975.

Both Alpha Metals in Jersey City, N. J., and KENCO Alloy and Chemical Co., Inc. in Addison, Ill., have developed test equipment for evaluating board cleanliness in accordance with MIL-P-28809. KENCO's equipment is called the "Omega Meter." It was selected for discussion because it was capable of testing larger circuit boards at the time of this report. The Omega Meter determines board cleanliness by direct measurement of the electrical resistivity of a polar and non-polar (deionized water and alcohol) wash solution, used to remove available contaminants from the surface of parts and assemblies. The wash solution is a semi-permanent part of the equipment, in that it is automatically self-regenerated to maintain high levels of purity. The equipment pumps the wash solution into a test cell, the proper quantity being based on the total surface area of the part to be tested. To perform a test, the part is immersed in the solution. The solution is continually agitated by a magnetically coupled stirrer at the bottom of the cell. Before the test is started, the minimum acceptable reading can be inserted into the equipment by moving an indicator dial to the corresponding reading on the meter.* When the test is performed, a second indicator will respond to the actual resistivity of the solution. If this reading falls below the preset value inserted before the test, a visual and audible signal will indicate a reject. The meter will indicate the actual measurement, and a built-in chart-recorder will provide a permanent record of the test (see Figure 21 for typical test chart). The time required to perform an entire test, including filling of the test cell, self check for purity, and actual measurement, is approximately 7 minutes.

The following is a summary of typical applications that demonstrate how the Omega Meter can be utilized to assure production and quality control of the P.C. assembly and soldering operation: (Ref 29)

a. Determining levels of residual ionic contamination present, after initial fabrication of bare printed circuit boards, resulting from plating, etching, etch resist removal, chemical cleaning and fusing operations.

b. Determining any ionic contamination resulting from environmental fallout during transportation, storage and handling.

c. Performing incoming Quality-Control inspection of electronic components and bare printed circuit boards prior to assembly and soldering.

d. Determining levels of contamination on printed circuit assemblies resulting from handling, assembly and component insertion prior to soldering.

---

*The minimum acceptable resistivity permited by MIL-P-28809 is 2×10^6 ohm-centimeters.

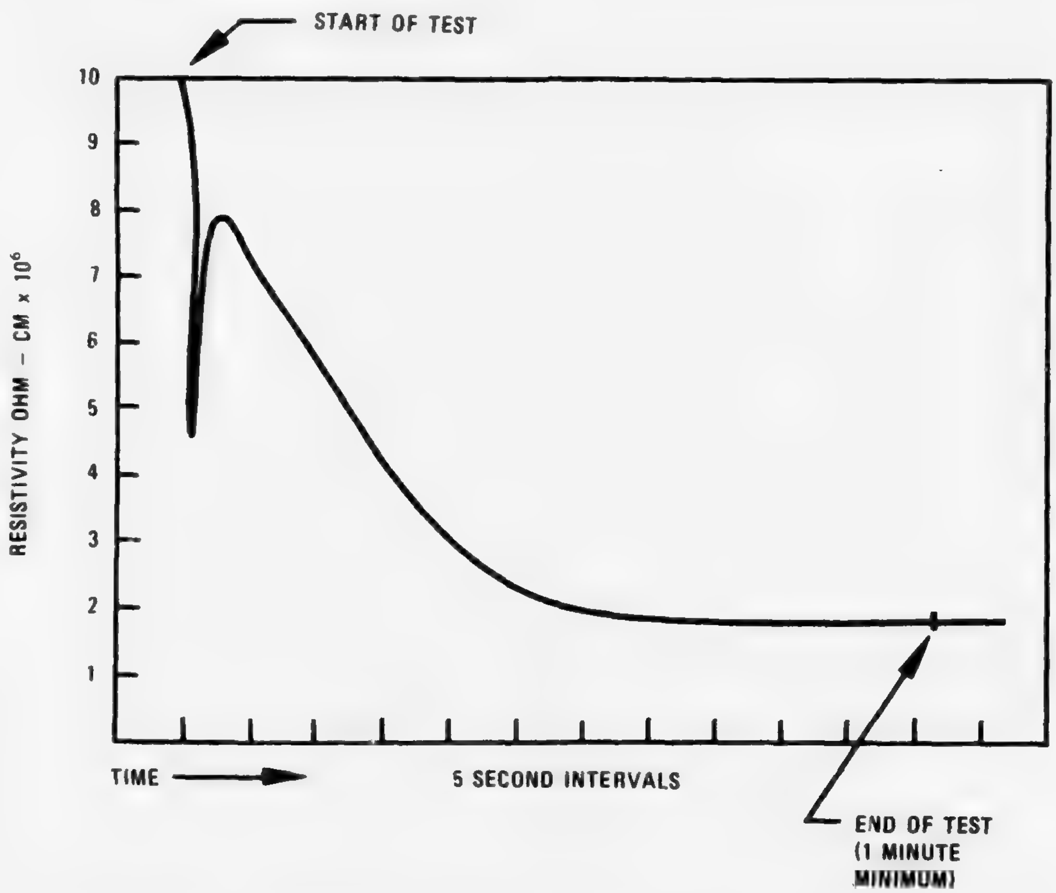


Figure 21. Typical Omega Meter print out of P.C. board cleanliness (as a function of solvent resistivity)

e. Evaluating various soldering fluxes, including data in determining a possible switch to the use of more effective water-soluble type fluxes.

f. Evaluating the cleaning capabilities of various flux remover cleaning solvents.

g. Determining the quantitative results achieved in removing rosin type fluxes via the "aqueous system" of removal.

h. Determining the results of various cleaning methods and processes, as well as evaluating the capabilities of various types of cleaning equipment.

i. Determining the level of cleanliness of printed circuit assemblies after soldering and cleaning.

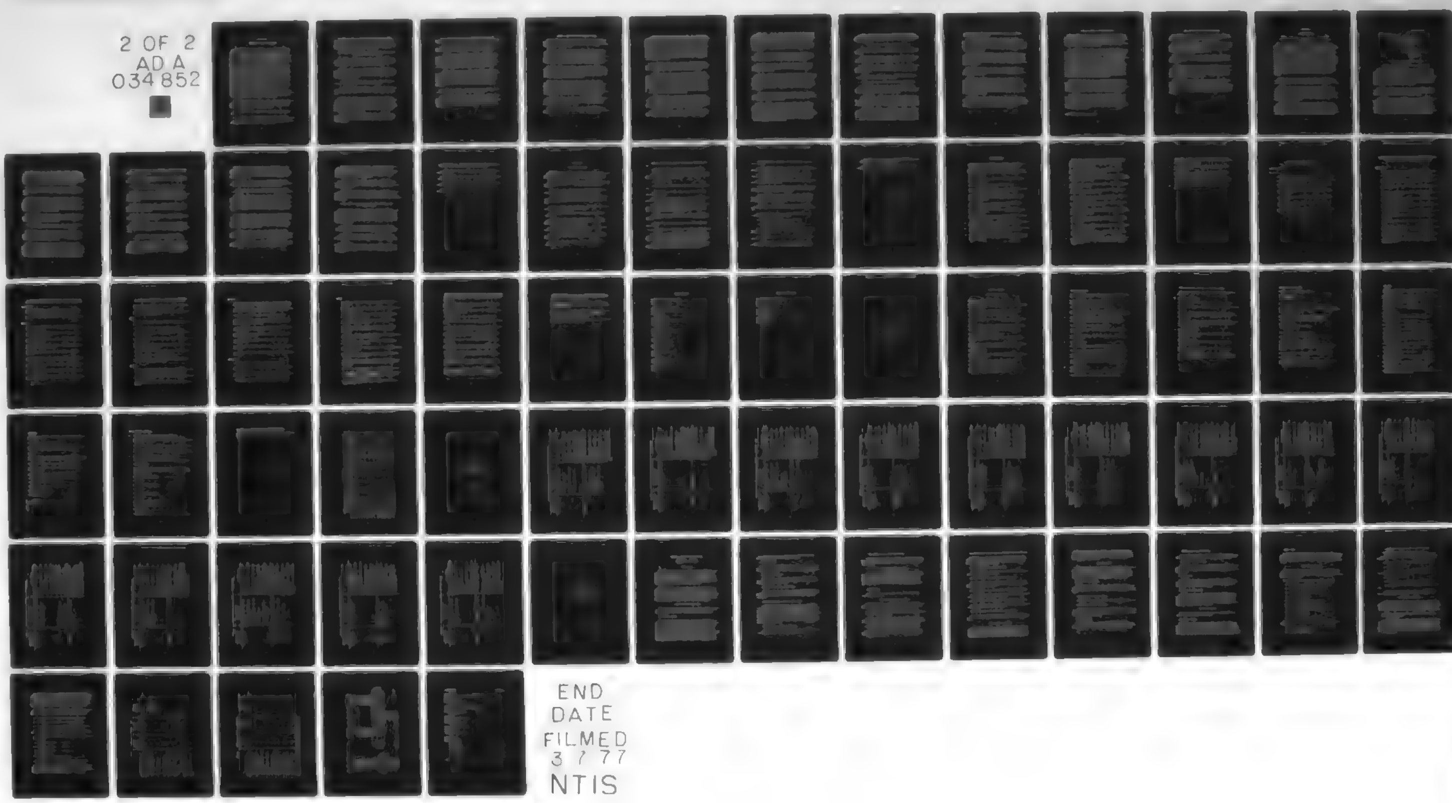
j. Determining the level of "available" surface ionic contamination on printed circuit assemblies soldered with rosin type fluxes when flux removal has not been employed.

k. Determining levels of cleanliness on surfaces prior to the application of conformal coatings and potting compounds.

l. Generally determining any ionic contamination resulting from many and varied sources on many and varied parts-components and assemblies-quickly, accurately, and nondestructively.

AD-A034 852 LOCKHEED ELECTRONICS CO INC PLAINFIELD N J F/G 13/5
THE DYNAMIC MEASUREMENT AND FUNCTIONAL INSPECTION OF SOLDER JOI--ETC(U)
DEC 76 DAAA21-76-C-0100
UNCLASSIFIED PA-TR-5005 NL

2 OF 2
AD A
034852



END
DATE
FILMED
3 7 77
NTIS

SECTION VIII

SUMMARY OF STUDY FINDINGS

Considerable attention has been focused on solder joints during the past twenty-five years. Numerous reports of studies concerning the metallurgy, reliability, and inspection of solder joints have been published during this period. As part of the literature search performed on this program, technical abstracts of hundreds of reports were reviewed. The conclusions reached in the majority of abstracts reflect the inspection philosophy that was prevalent at the time. For example, prior to 1965, the majority of reports issued, supported the validity of 100% visual inspection. Between 1965 and 1970, the published reports reflect a period of uncertainty with respect to visual inspection criteria. It was during this period that industry began running tests to determine what were the primary failure modes in solder joints, when tested to actual program requirements. Prior to this testing concept, solder joints had been assessed in terms of their mechanical strength. Shock, vibration, tensile and shear strength tests had confirmed that bright, shiny joints, free of porosity and inclusions, were far stronger than joints with surface imperfections. What had been overlooked by these early test programs was the fact that the levels of shock, vibration, etc., required to cause failure of "cosmetically imperfect" joints was far in excess of what the joint would experience under actual operating conditions. On the other hand, when joints were life tested under operating environments, it was discovered that there was a definite mode of failure within these limits. Testing demonstrated that joints fail far more readily as a result of thermal fatigue, as compared to mechanically induced stresses. As a result of these findings, thermal cycling unofficially became the standard test for evaluating P.C. solder joints.

Temperature cycling tests performed on solder joints have had a tremendous impact on the inspection philosophy for P.C. soldered connections. Testing within operational limits now indicates the "cosmetically imperfect" joints actually outperform the "perfect" joint in most areas.

These revelations have had an effect in two significant quality assurance areas:

a. The credibility of visual inspection criteria has been seriously questioned.

b. The advantage of automated infrared and optical equipment for detecting surface imperfections on solder joints is now uncertain.

The majority of reports issued between 1970 and the present reflect a growing acceptance for the elimination of visual inspection for solder joints. The emphasis has shifted to the area of process control. The conclusions reached as a result of this study program reflect the present attitude of a significant segment of the military electronics industry with regard to the manufacture and acceptance of printed circuit solder joints.

THE VALUE OF VISUAL INSPECTION AS A METHOD FOR ASSESSING THE QUALITY OF SOLDER JOINTS

There is wide acceptance within the industry for the attitude that visual inspection is an ineffective method for determining solder joint quality. The inability of inspectors to predict which joints will survive environmental tests was demonstrated by test programs documented in this report.

a. Visual inspection may do more harm than good in terms of assuring the quality of solder joints. Joints rejected for various imperfections must be either touched up or reworked, and reinspected for acceptance. By subjecting the joint to the soldering temperature (400°F to 500°F) a second time, it has been degraded in two respects:

1. The effects of thermal shock on P.C. plated-thru holes are cumulative, and affect the subsequent thermal life of the plating.

2. The time-temperature relationship, required to keep the thickness of the intermetallic layer to a minimum, is altered by resoldering. The reworked joint will be more brittle as a result of having a thicker intermetallic layer.

b. In light of the inefficiency and possible degradation resulting from visual inspection, the acceptance of solder joints, based on their ability to survive an inspection for approximately 15 negative (reject) criteria, under 6X magnification, on both sides of the P.C. board, is obviously counterproductive, without even considering rework and reinspection costs. It has been estimated that the cost of visually inspecting a solder joint exceeds the cost of manufacturing by a factor of four to one.

c. It is possible to manufacture highly reliable P.C. assemblies with absolutely no visual inspection of connections after soldering. Many foreign and some U.S. commercial suppliers have already demonstrated success with this approach.

It is not reasonable to assume that military programs will adopt this philosophy without conducting their own test programs; however, the elimination of visual inspection for solder should be considered as an achievable objective.

d. One-hundred percent visual inspection of solder joints should be retained on current Hi-Rel programs; however, the inspection philosophy must be altered if productivity and reliability are to be enhanced. For example:

1. The inspection philosophy should be one of acceptance rather than rejection. Inspectors should be trained to recognize the attributes that constitute a reliable joint without regard to cosmetic appearance. All of the test programs documented in this report have demonstrated that only two criteria, wetting and adhesion area, are useful for visual inspection purposes. The concept of wetting should be thoroughly understood by all inspectors and should serve as the only basis for visually accepting or rejecting solder joints.

2. Visual inspection should be limited to the bottom side of the board, and should be performed with the unaided eye. There is no advantage to inspecting the component side of the board, because testing has demonstrated that partially filled plated-thru holes, with component leads, perform as well as filled holes. Holes without component leads need not be inspected at all, because testing has shown that unfilled holes, or partially filled holes, that presently qualify as rejects, actually survive longer under environmental extremes.

Magnification is not required to determine if wetting is acceptable, and may actually be undesirable, depending on the individual inspector.

Experience has shown that magnification in excess of 4X can cause extreme eye strain. In some cases headaches create emotional stresses that further lessen the effectiveness of the inspector and add to the time required to complete the inspection. What is more, the type of defects that are detectable at 6X magnification are primarily pinholes and small voids, which have no bearing on joint reliability.

COSMETIC IMPERFECTIONS IN SOLDER JOINTS

The majority of items listed as defects in most Hi-Rel soldering specs are purely cosmetic attributes and have no effect on the function or reliability of solder joints. The following is a summary of conclusions derived from the test programs referenced in this report.

a. Porosity. Any joint that does not display a bright, shiny appearance is usually rejected under this category. A common problem created by this inspection attribute is the acceptance of joints soldered to gold-plated surfaces. Finished joints are generally gray in appearance, due to the formation of tin-gold intermetallics; however, gold is a material that wets easily, and the joint is generally acceptable on this basis alone. Unfortunately, inspectors must assure that all spec requirements are adhered to and, as such, the joint is rejected.

The reworking of this type of defect, in order to achieve a shiny surface, typifies the harm that can result from visual inspection. Meniscograph testing has shown that by removing the solder and reworking the joint with fresh solder, an alloy is formed between the tin, gold, and copper that is far less solderable and considerably more brittle than the original interfacial bond. The reworked joint is now considerably less reliable than before.

True porosity in solder joints is evidenced by minute voids which are generally distributed uniformly throughout the solder. The tests that have been performed on such joints indicate that they survive longer than perfect joints when tested under extreme thermal conditions. Internal stresses generated during thermal expansion and compression of the component lead, plated-thru hole and the solder, tend to be relieved and uniformly distributed by the porosity. Testing has not indicated any validity for rejecting joints due to porosity.

b. Pinholes and Voids. Just as in the case of porosity, pinholes and voids tend to relieve internal stresses. Analysis has further indicated that cracks which develop in joints at destruct test levels are actually curtailed by the presence of a void in the path of the crack.

Voids which expose the bare conductor lead, or plated-thru hole adjacent to the lead, are a valid basis for rejection because they indicate poor wetting and they reduce the adhesion area.

c. Unfilled or Partially Filled Plated-Thru Holes. The requirement that plated-thru holes (PTH) be filled with solder is obsolete. Rome Air Development Center (RADC), the Institute of Printed Circuits (IPC) and NASA have officially taken the position that PTH's need not be plugged with solder. This change in position is a result of extensive life testing of P.C. solder joints by various industry and government agencies. These tests have repeatedly demonstrated that the PTH is more reliable if left unfilled. The literature search did not uncover any documented evidence indicating why the MIL-Specs require filled PTH's. The judgment derived through discussions is that filling the hole with solder may reinforce a weak PTH corner on the component side of the board. If this is the case, then it is uncertain why the Spec tolerance allows for a 25 percent recession fillet height.

Thermal cycling and vibration tests performed at destruct levels demonstrated that the solder, not the PTH, or the solder bond between the lead and the PTH, is the first to fail. At typical operational levels partially filled and fully filled PTH's meet military requirements with a high margin of safety.

d. Cold Solder Joints. This term has been grossly misapplied in most military solder specifications. It has been mistakenly used to describe a joint that has been disturbed during cooling and, as a result, has a chalky or wrinkled surface texture. In reality a cold solder joint is generally perfect in terms of cosmetic appearance. The joint is formed by flowing solder that has barely melted over a surface that has not attained sufficient temperature to produce a complete intermetallic bond. The finished joint is extremely shiny in appearance because the solder was not hot enough to absorb oxygen from the ambient air. Since this type of defect is virtually undetectable the term "cold solder" has no meaning in terms of a visual inspection attribute.

e. Disturbed Solder Joints. This type of defect occurs when the rate of cooling is abnormally slow and the component lead is moved during solidification. Cooling may be retarded by poor thermal conductivity of the component parts, or as a result of a large thermal mass in the soldering area. The type of disturbance experienced by components being shaken by conveyor movement during and after wave soldering is generally not sufficient to produce this defect.

Joints that have been disturbed to the point that the reliability is questionable will automatically be rejected because the rough, flaky appearance of the solder will prevent the inspector from determining if wetting is adequate.

f. Solder Peaks. This type of defect has no bearing on the joint reliability. The defect is caused by the high surface tension forces of the liquid solder that tend to pull solder off the wave at the point of exit. Peaks that are of sufficient height to cause possible shorting to adjacent circuit boards after installation in the equipment should naturally be removed. Peaks that present a hazard to personnel during handling of the board should also be removed. The method of removal should not require resoldering of the entire connection. Peaks should be removed either by spot touching with a hot iron or by clipping with special carbide cutters.

g. Excessive Solder Which Obscures the Connection Configuration. This type of soldering condition prevents the inspector from determining if wetting has occurred. Adhesion area cannot be determined if the component lead is not visible. Excessive solder is, therefore, a valid basis for rejection.

h. Rosin Solder Connection. Any evidence of flux residue at the time of visual inspection indicates that the cleaning process is out of control. If the rosin constitutes a void in the adhesion area between the parts being joined, then rework will be required.

i. Dewetting. Dewetting on circuit streets or adjacent to plated-thru holes, or any other area that does not affect the adhesion area of parts being joined with solder, should not require rejection and touchup. Corrective action to improve processing is indicated, but this should not be accomplished by reflowing the entire board and, thereby, degrading the critical bond areas. Dewetting in the adhesion area requires rejection and rework of the joint. Rework must consist of removing the original solder, cleaning the hole and component lead, and resoldering.

j. Visible Bare Conductor Within Solder Joint Area. This is an unnecessary inspection attribute that does more harm than good. As long as the requirements for wetting and adhesion area are understood by inspectors, the "visible bare conductor" attribute is not required.

A typical problem area resulting from this attribute is the soldering of gold-plated Kovar pins. In many cases, with hermetically sealed modules, the pins end up extending farther than normal beyond the bottom surface of the board. Lead cutting is undesirable because of the risk of cracking glass-to-metal seals, and component side spacers are not always possible. As a result, the pins are soldered as is, and even though there is an acceptable fillet between the pin and the PTH, any evidence of gold at the tip of the pin will result in a rejection. Resoldering of gold plated surfaces degrades bond strength and, as a result, the reworked joint is less reliable.

k. Insufficient Solder. This inspection attribute is harmful because of its subjectivity. Testing has shown that joint life is enhanced by keeping solder quantity at minimum levels. Wetting and adhesion area are sufficient to determine joint acceptance.

NONDESTRUCTIVE TESTS FOR SOLDER JOINTS

In order to be useful as a production test, capable of accepting or rejecting solder joints, the test program must be capable of meeting all of the following objectives:

a. The program must be capable of performing a production type test that measures or evaluates the desired characteristic (conductivity, resistance, rf impedance, etc.) of individual joints on a 100% basis.

b. The test must be capable of assessing joint reliability. That is, it must be capable of detecting the legitimate defects (such as dewetting) that may not affect performance initially, but may fail eventually as a result of thermal or mechanical stress.

c. It must be capable of detecting defective joints without degrading the reliability of all other joints as a result of the test.

d. The test results must not require subjective visual interpretation.

The literature search and discussions with experts in the field of nondestructive testing did not uncover any test method that could satisfy all of these objectives. The following describes the major areas of difficulty that must be overcome by nondestructive solder joint test programs:

a. Electrical Tests. All of the tests in this category, such as resistance, R.F. noise detection, R.F. impedance measurement, etc., fail to be effective due to the inaccessibility of individual joints. The variation in electrical characteristics between good and bad solder joints is so slight that it will be masked by the normal tolerance variations of interconnecting circuitry and components.

b. Ultrasonic and Acoustical Noise Measurement Techniques. Testing of this type can be performed utilizing a proximity probe to couple the energy to individual joints. Although loose wires are detectable, the majority of joints will be rejected due to the detection of small internal voids. Voids of this type are a natural occurrence in soldering, and do not constitute a legitimate basis for rejection. The critical soldering parameters of wetting and adhesion area

are not accurately evaluated by this method and, therefore, the reliability of accepted joints remains uncertain.

c. Optical Scanning Techniques. Optical techniques are useful for the inspection of unassembled P.C. boards because each physical characteristic of the board is controlled to tight tolerances. Optics can be used to determine the proper location of a hole, proper diameter of a hole, and even the concentricity of the hole within its pad area. This is accomplished by correlation techniques using stored computer data.

These techniques are not effective for solder joints because it is virtually impossible to control the physical characteristics of the finished joint within precise limits. The placement of the component lead, the length of the component lead, the quantity of solder and the shape of the fillet all vary in combination to the extent that even a broad range of reasonably consistent measurement signals is impossible.

d. Infra-Red Photography. This approach surpasses all others in terms of the significance of the test results with regard to the reliability analysis capabilities. Its major drawbacks are in the areas of cost, visual interpretation, and use as a production test.

To be effective, the test should be run on a functional piece of hardware. The assembly is photographed using high speed I.R. sensitive film. After developing, the segments of the film, corresponding to various timing modes of the assembly, are viewed and analyzed by skilled inspectors. Abnormalities in the solder joint which could affect reliability show up as differences in color in the area of the defect. Experienced analysts are capable of determining whether the defect is a crack in the solder, crack in the PTH or a void within the solder joint adhesion area.

e. Other Measurement Techniques. Other measurement techniques such as x-ray, neutron and proton radiography, and pulsed laser harmonic detection, were also examined as part of the study; however, all of these techniques suffered to a greater extent from the drawbacks experienced by the above methods. For this reason they were not discussed in detail in this report.

DYNAMIC TESTING OF SOLDER JOINTS

Without a suitable measurement technique for assessing the reliability of solder joints, the value of dynamic testing is greatly diminished. The theory behind dynamic testing is that potentially unreliable solder joints can be located by accelerating and inducing failure during the production test. The most common dynamic condition used for this purpose is vibration; however, thermal cycling is sometimes used on a sample basis.

The problem with dynamic testing is that there is no easy method for determining what the optimum levels of vibration or number of thermal cycles should be for the test. The theory also assumes that there is a wide margin of safety between good and potentially bad solder joints. The literature study did not reveal any evidence to support this assumption. The major question concerning dynamic testing is: What is its effect on the reliability of those joints that survive the test? Have they been degraded by the test so that they are now potential defects? The question was posed to several Manufacturing and Quality Assurance experts during the course of the study.* Of those contacted, only Joseph Keller, Supervisor of Advanced Manufacturing Technology for Martin Marietta, Orlando Division, had extensive experience in the area of dynamic testing. Mr. Keller is of the opinion that the reliability of solder joints can only be assured by controlling the process. Dynamic testing is merely a tool for demonstrating that this philosophy is correct (Ref b).

Dynamic testing can be best utilized as a process qualification test that is performed on a first article and recurring basis. The test should also be performed when major elements of the process are modified. The tests should consist of both vibration and temperature shock cycling, and should be considered destruct type. Test levels should be dictated by realistic hardware requirements, and circuit function should be monitored continually during the test.

Dynamic testing should only be considered as an interim measure. The ultimate objective of these programs is to demonstrate to the military that highly reliable solder joints can be guaranteed if the process is controlled. It is also hoped that dynamic testing can be used to demonstrate that solder joint reliability can be further improved if present constraints that prevent the manufacturer from using the best possible materials and processes are waived in lieu of an approved process.

---

*Refer to Telephone Conference Report.

PROCESS CONTROLS FOR SOLDER JOINTS

Recent developments in the area of solderability testing and cleanliness testing have, for the first time, provided Quality Assurance engineers with the necessary tools to effectively control the soldering process.

The development of the Meniscograph enables fast quantitative solderability testing of actual production hardware at any point in the procurement and manufacturing cycle. Similarly, the development of equipment designed to quantitatively test P.C. boards for cleanliness, before and after assembly, offers tremendous possibilities as a process control tool.

The literature search indicates a major shift in emphasis in the direction of process controls since 1970. Fewer companies, including the divisions of Lockheed Aircraft Corp., are investing in expanded test programs to evaluate solder joints.

The effectiveness of a controlled soldering process has been demonstrated on recent military programs. This is indicated by the increasing number of requests being generated by resident DCAS officers to reduce visual inspection requirements on solder joints. These requests are based on extremely low solder defect rates compiled over significant production periods at facilities where process controls have been enforced.

Manufacturers of wave soldering equipment and related peripheral equipment appear confident that hardware suppliers will obtain wider military acceptance for a controlled soldering process. In this regard, the major effort is being directed toward the development of better pumps for intermixing tinning oil with solder; improved methods for depositing highly active rosin and water-soluble fluxes; and high speed carbide cutters for the mass trimming of component leads.

SECTION IX

CONCLUSIONS

VISUAL INSPECTION OF SOLDER JOINTS IS INEFFECTIVE

There is wide acceptance within the military electronics industry of the premise that visual inspection, based on criteria presently prescribed by military soldering specs, is ineffective and in some cases detrimental to the reliability of solder joints. This opinion is the result of several industry-sponsored test programs designed to evaluate solder joints on both a functional and visual inspection basis. In all cases, visual inspection failed to come even close to predicting which joints would survive or fail when subjected to realistic environmental tests. The lack of correlation between the predictions of visual inspection and functional test results indicates that a significant number of joints are being unnecessarily reworked on typical hardware programs. In addition to increasing production and reinspection costs, the reworking operation may degrade reliability by upsetting critical parameters that were optimum in the original joint. Testing has proven that, during the solder removal operation, the brittle intermetallic layer at the interface is thickened. Resoldering further increases the thickness of this layer, so that the reworked joint may be weakened by the process.

Visual inspection can be effective if the determination is based on proven functional criteria. Testing has demonstrated that the only visible attribute of a solder joint that correlates with functional test results is the element of wetting.

The term "wetting" is seldom used in military soldering specs, and yet it is referred to extensively in articles and reports dealing with the mechanics and metallurgy of solder joints. Good wetting is evidenced by a thin layer of solder that has spread evenly over the parts being joined. The end of the spread area seems to blend with the contour of the underlying surface. A small fillet of solder between the joining parts is discernible everywhere within the common solder spread area (see Figure 22).

Inspectors can be easily trained to recognize good wetting even without magnification; however, military soldering specs must be upgraded to provide inspectors with these types of effective criteria. Instead of relying on a subjective interpretation, based on a comparison with photographs, the inspector must be able to apply his knowledge of soldering objectively to all situations. Joints should be checked for their good qualities rather than for their cosmetic appearance.

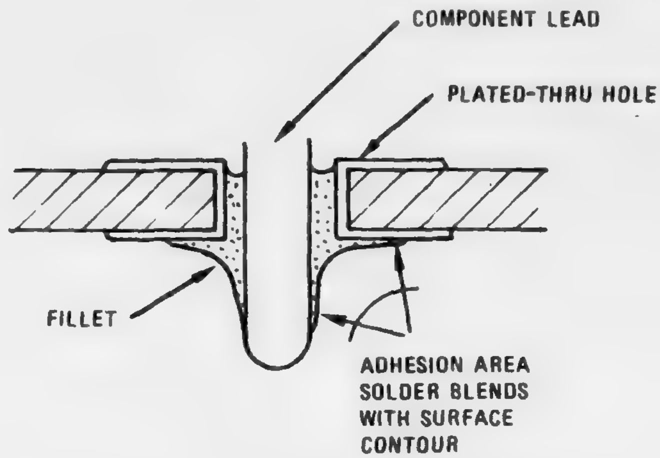


Figure 22. Visual attributes of wetting

VISUAL INSPECTION CRITERIA MUST BE REDEFINED

The visual inspection attributes specified in Hi-Rel soldering specs are primarily a listing of defects for which a joint should be rejected. The list of defects has not been significantly altered in the past 15 years. A review of published solder joint test programs conducted during this same period indicates that, prior to 1965, these inspection criteria were supported by the test results. However, the majority of programs conducted after 1965 appear to contradict the validity of these same criteria. The explanation lies in an analysis of the test philosophies employed on the various programs.

Prior to 1965, solder joints were evaluated in terms of their mechanical strength. The reliability of the joint was predicated on its ability to withstand extreme levels of shock and vibration. In this regard, the soldering defects remain a valid basis for comparing the reliability of joints.

Between 1965 and 1967 several manufacturers of P.C. boards began running tests designed to demonstrate the improved reliability of plated-thru holes. These tests were primarily thermal cycling and vibration. The test levels were based on realistic hardware requirements. The test programs had a significant impact on the philosophy of testing solder joints. The results revealed that, although all of the joints tested survived realistic levels of vibration, a significant number of joints failed as a result of thermal cycling. Subsequent test programs resulted, with the emphasis being placed on the total

functional performance of the joint rather than on mechanical strength alone. The test results indicate that tradeoffs are required to optimize the functional reliability of the solder joints. Some of the physical attributes which enhance the mechanical strength of a joint actually impair its ability to endure thermal cycling. For example, joints with voids, pinholes and porosity are mechanically weaker than joints that are free of these defects; however, these same defects tend to relieve internal stresses generated during thermal cycling.

Thermal cycling has been established as the primary mode of failure in P.C. solder joints since 1967. However, the MIL-Spec criteria have not been modified to permit the tradeoffs required to optimize joint reliability in this respect.

The criteria used to evaluate joint reliability should be tailored to the functional requirements that are dictated by the program. For example, if the equipment will experience high levels of shock and vibration, such as in a tank, then joints should be free of porosity and voids. If, on the other hand, the equipment is part of a missile where, for the majority of its life, the primary dynamic forces result from changes in storage temperature, the joints will be enhanced by the presence of minor inclusions.

Basic soldering specs should include only those criteria which are common to all program requirements, that is, evidence of wetting and adhesion. Any additional requirements deemed necessary to meet special program requirements should be invoked on an amendment basis.

DYNAMIC TESTING IS LESS EFFECTIVE THAN VISUAL INSPECTION FOR ASSESSING THE RELIABILITY OF SOLDER JOINTS

Dynamic testing is only effective for evaluating joint reliability on a destruct basis. By subjecting joints to functional levels of temperature cycling, shock and vibration, the adequacy of the design and manufacturing process can be demonstrated. When used as a production test, dynamic testing tends to degrade the reliability of the joints under test.

Metallurgical analyses and accelerated life tests have proven that the solder joint is a limited life item. Even under static conditions, the joint will ultimately fail as a result of internal stresses that were induced during cooling and solidification of the solder. The failure mechanism involved in this phenomenon is commonly referred to as "creep." The internal stress within the solder actually pulls apart and rearranges the atomic lattice of the solder until failure occurs. Under static conditions this would require several thousand years;

however, when the internal stresses are supplemented with externally produced forces, the margin of safety is continually reduced. The degrading effects of external forces are cumulative.

Dynamic testing exposes solder joints to forces the reduce the life of the joint. The reliability of joints that survive the test is less certain than it was before the test was performed.

NONDESTRUCTIVE TESTING OF SOLDER JOINTS IS IMPRACTICAL AS A PRODUCTION TEST FOR MOST HARDWARE APPLICATIONS

Technology has yet to provide a cost effective method for performing meaningful measurements on production solder joints. Electrical measurements are unfeasible because of the inaccessibility of individual joints on completed assemblies. Ultrasonic and acoustical techniques suffer from similar interference problems.

The nondestructive techniques which yield the most useful data, such as infra-red photography, tend to be the most costly and time-consuming. They also require highly skilled visual interpreation which is in opposition to the objectives of this study program.

The literature search indicates that efforts to develop nondestructive production tests for solder joints have diminished in recent years, as the emphasis has shifted to improved process controls.

Functional testing of P.C. assemblies, during a thermal excursion to an elevated temperature (one cycle), has been employed on several high-volume commercial programs. However, there is an indication that the level of testing is being reduced to a lot-sampling basis as better process controls are incorporated.

RELIABILITY CAN BE BEST ASSURED BY MEANS OF A QUANTITATIVELY CONTROLLED SOLDERING PROCESS

The reliability of a solder joint cannot be determined by visual inspection or nondestructive test. On the other hand, reliability can be enhanced by applying proven concepts to the soldering process in a manner that will yield maximum results. By controlling the quality of the process, the confidence in the quality of the finished solder joint is more certain than if determined by present visual criteria.

The process control concept has always been valid; however, it was not achievable until as recently as 1973. Since then, technology has provided Quality Assurance engineers with the necessary equipment to perform quantitative measurements of critical parameters at any point in the manufacturing cycle. The only constraints that exist presently are the Military Soldering Specifications themselves.

Manufacturers are confident that by demonstrating their capability to produce better joints, as well as providing the government with more meaningful control data, existing constraints will eventually be removed.

SOLDERABILITY AND CLEANLINESS ARE THE KEY ELEMENTS THAT MUST BE CONTROLLED TO PRODUCE RELIABLE SOLDER JOINTS

Controlling the reliability of P.C. solder joints must begin at the design stage. Design engineers must be fully aware of the manufacturing and quality control process, and utilize this knowledge in the selection of components. For example, if completed boards are to be sample-tested for cleanliness per MIL-P-28809, then all components must be capable of being immersed in a water-alcohol solution. Components which cannot withstand immersion must be identified so that they can be processed separately by the manufacturing branch.

During prototype development, solderability test data should be compiled on all components. The data can then be translated into acceptance standards for controlling the manufacturing process. During this same period Manufacturing Engineers should be utilizing solderability testing as the basis for selecting the solvents, oils, solder and flux that will yield maximum wetting during the wave soldering operation. During production, process controls should consist of the following elements:

a. Solderability Testing at Receiving Inspection on a Sample Basis. Samples must meet the minimum wetting force and minimum wetting time specified on the procurement document or RITR (Receiving Inspection Test Requirement). Testing should be performed using a Meniscograph or equivalent tester.

b. Cleanliness Testing at Receiving Inspection on a Sample Basis. Unassembled P.C. boards should also be tested for cleanliness in accordance with MIL-P-28809 using an Omega Meter or equivalent test method.

c. Solderability Testing During Storage. Components and P.C. board test coupons should be withdrawn from stock and tested for solderability on a scheduled, sample basis. The test schedule should be determined on an experience basis. Degradation of solderability during storage may require improvements in handling procedures, component packaging materials or better environmental control of ambient atmosphere.

d. In-Process Solderability Testing. Components should be selected on a random basis from the production line during lead cutting, lead forming and component insertion operations. The testing should be integrated with the normal surveillance operation.*

e. Post Soldering Cleanliness Test. Following wave soldering, and solvent cleaning to remove flux and oil residues, sample assemblies should be tested for cleanliness in accordance with MIL-P-28809. If assemblies are to be stored for long periods prior to conformal coating, the test should be repeated immediately before coating.

VISUAL INSPECTION CRITERIA FOR PROCESS-CONTROLLED P.C. SOLDER JOINTS

Process controls are utilized on a statistical sample basis; therefore, 100% visual inspection is still required for final acceptance. However, the level of inspection can be reduced as much as 80% without compromising the quality of the final assembly. The following criteria are based on the results of the functional test programs documented in this report. Only those physical characteristics of a P.C. solder joint which have a proven correlation with a functional requirement are listed.

a. Visual inspection of solder joints should be performed on the noncomponent side of the board only. Inspection can be performed with the unaided eye or with magnification not to exceed 4X, depending on inspector preference.

b. Joints should be inspected for evidence of wetting and adherence as indicated by the solder blending with the contour of the parts being joined, and spreading beyond the interface area. Adherence is indicated by a visible fillet

*In process solderability tests performed at Martin Marietta in Orlando, Fla. revealed that certain operators and technicians must wear gloves at all times because of the unusually high level of solerability contaminants found in their perspiration.

between the joining parts. Solder coverage can vary in thickness and evenness, as long as the contour of the parts and the fillet remain visible.

c. Clean pinholes, voids or depressions on the surface of the solder are acceptable.

d. Plated-thru holes, with or without component leads, are not required to be filled with solder.

e. Dewetting on circuit streets or in plated-thru holes without component leads is acceptable.

f. Incomplete wetting at the tip of component leads and edges of circuit pads is acceptable.

SECTION X

RECOMMENDATIONS

Based upon the findings of the solder test programs referenced in this report, and using this information in concert with the literature search and industry survey conducted during this study program, the following are recommended:

a. Modify P.C. solder joint acceptance criteria to eliminate the requirement for solder plugs, "C" wires or "Z" wires in plated-thru holes under the following conditions:

1. P.C. board test coupons to include a continuity loop of plated-thru holes that is dynamically tested on a sample basis for acceptance.

2. Testing would consist of monitoring the resistance of the continuity loop during exposure to 500°F for 20 seconds, followed by 100 thermal shock cycles. Temperature extremes are to be dictated by program hardware requirements.

b. Modify P.C. solder joint visual inspection requirements to allow inspection from the non-component side of the board only.

c. Modify inspection requirements to allow inspection of joints without magnification.

d. Eliminate restrictions on the use of activated fluxes, providing that soldered boards are sample-tested to meet the cleanliness requirements of MIL-P-28809 following normal cleaning operations.

e. Modify inspection criteria to allow the presence of pinholes and voids in all areas except the solder fillet between joining parts.

f. Modify inspection criteria by eliminating reference to all misnomers and subjective terms, such as cold solder, porosity, disturbed solder, pits, scars and dents.

g. Modify soldering specs to include an explanation and description of "wetting" and "adherence."

h. Modify solder joint reject criteria to include only the following type of defects:

1. Solder bridging between printed circuit streets or pad areas.

2. Solder peaks that reduce the distance between an element of one circuit and an adjacent circuit or conducting material below the minimum specified on the printed wiring board assembly drawing.

3. Cracks in the solder.

4. Excess solder that obscures the presence of a fillet between joining parts.

5. The presence of any foreign matter such as dirt, flux residue, broken wire strands, etc.

i. Establish a new military standard for solderability testing based on the quantitative measurement of wetting force and wetting time.

j. Modify soldering specs to include provisions for the qualification of the P.C. assembly operation, based on statistical sampling of components for solderability and cleanliness testing at various stages of the manufacturing cycle, and successful completion of first article tests.

k. Include provisions for modifying the P.C. assembly process based on successful completion of functional dynamic tests, such as thermal shock and vibration.

l. Include provisions for scheduled requalification based on functional dynamic testing.

FOLLOW-UP TESTING AND EVALUATION OF LITERATURE STUDY FINDINGS

A test program is recommended for evaluating the findings of this report. The program would include the design and fabrication of special P.C. board assemblies using components and materials typical to military hardware applications. The objectives of the test program would include the following:

a. A comparison of P.C. solder joint reliability and cost, manufactured in full accordance with MIL-STD-1460(MU), vs a statistically controlled manufacturing process with simplified visual inspection after soldering.

b. Establishing realistic criteria for the inspection and acceptance of P.C. boards, including:

1. Design of a standard test coupon that is manufactured with each board that can be dynamically tested for plated-thru hole quality.

2. Solderability test requirements based on comparison testing of various plating materials and thicknesses, and vendor cleaning practices.

c. Evaluation of the Meniscograph solderability tester and the Omega Meter (MIL-P-28809) cleanliness testers as:

1. Manufacturing tools for selecting optimum flux and cleaning solvents, adjusting wave soldering conveyor speeds to maximum rates and evaluating the advantages of various new materials and processes.

2. As a quality control tool for accepting or rejecting procured parts based on specified solderability and cleanliness requirements. Monitoring these characteristics throughout the storage, assembly, wave soldering and post cleaning phases of the production cycle.

d. Preparation of a process control plan specifying internal Q.A. and DCAS inspection points, and the statistical sampling plan to be utilized at control points.

e. A comparison of visual inspection defect rates after solder, using MIL-STD-1460 vs simplified inspection criteria.

f. A comparison of solder joint performance based upon:

1. Dynamic testing to typical military hardware levels.

2. Correlation of visual inspection results, with dynamic test results for rejected joints that were reworked, rejected joints that were not reworked, and accepted joints.

3. Dynamic testing to destruct levels of thermal shock cycling and vibration.

g. A comparison of actual manufacturing and inspection costs for P.C. board assemblies conforming to MIL-STD-1460(MU) vs controlled process.

h. Analysis of test results and final recommendations for incorporating the findings in future military hardware programs.

A suggested test program for accomplishing the above objectives is described in detail in Appendix C of this report.

BIBLIOGRAPHY

1. "Printed Wiring Soldered Electrical Connections," Final Report, July 1959, Contract No. DA-36-039-SC-78167, Fort Monmouth, N.J.

2. J.D. Keller, "Solder Joint Inspection Versus Process Control Attention," Technical Paper Synopsis, 1820 Winchester Drive, Winter Park, Fla., 32789

3. J.D. Keller, "Criteria for Soldered Connections-Metallurgical Completeness" (see Item 2)

4. H. Manko, Solders and Soldering, McGraw-Hill, 1964

5. J.D. Keller, "Can the U.S. Afford the Cosmetic Look in Soldered Joints-Part I and II," Assembly Engineering (Oct and Nov 1973)

6. "Electron Beam Microanalysis and Scanning Electron Microscopy of Solder Joints on a Printed Circuit Board," Raytheon Co., NFMSE, Report No. AMR-2997

7. J.L. Waszczak and J.D. Keller, "The Case for Unfilled PTH's," Electronic Packaging and Production (Oct 1973).

8. R.L. Johnson, "To Wick or Not to Wick," Electronic Packaging and Production (Dec 1965)

9. A.M. Jackson, "Evaluation of Printed Wiring Board Plated-Thru Holes Over Temperature Extremes," NASI-9000(Feb 1971)

10. J.S. Schiavo and R.M. Means, "Reliability in Multilayer PC Fabrication," Electronic Packaging and Production (Jan 1976)

11. R.O. Johnson, "Reliability in Soldering," National Electronic Packaging and Production Conference Proceeding (June 6, 1963)

12. R.H. Hronik, S. Devine, P.A. Thompson and W.M. Verbeck, "Investigation of Printed Circuit Board Solder Joints," I.R.E. Weson Convention Record (1959)

13. J. Bilinski and D. Treffs, "Nondestructive Testing of Electronic Components," National Symposium on Nondestructive Testing of Aircraft and Missile Components (Feb 16-18 1960), San Antonio, Texas, Proceedings, p. 11-1 to 11-11

14. D.J. Abel, "Optical Scanning-What You See is What You Get," Instrument and Control Systems (Feb 1975)

15. L.R. Judd and T.J. Magee, "Tolerance Studies for Infrared Production Testing of Electronics," Nondestructive Testing Symposium, Proceedings, Los Angeles, Cal. (Feb 1965)

16. D.J. Abel, "Optical Methods Measure Qualities," Instruments and Control Systems (April 1975)

17. "Strength of Soldered Joints," Report No. 40-56, National Research Council, Ottawa, Canada (March 1960)

18. R.D. Bryant, "Solder Joint Imperfections vs Reliability," Final Report, Autonetics Division of Rockwell International (Feb 1962)

19. H.M. Abbott, "Inspection Methods for Electrical Solder Connections," Literature Evaluation, LMSC (April 1965)

20. "Solder Wicking Effects on Flex Life of Soldered Stranded Wire Terminations," Contract No. DA-01-021-AMC-11436(Z), Martin Marietta Corp., Orlando, Fla. (March 1966)

21. J.P. Chryst and R.D. Barron, "Effects of Environmental Testing of Visible Printed Wiring Anomalies," Martin Marietta Corp., Orlando, Fla. (Dec 1969)

22. W.P. Wood, "A Reliability Analysis of the Solder Joint (Machine Made)," ASME Publication (Jan 1973)

23. "The Effect of Solder Fill Quantity on Plated-Thru Holes," Martin Marietta Corp., Orlando, Fla. (Oct 1972)

24. D. Mackay, "The Meniscograph Method of Solderability Measurement," The General Electric Co., Ltd., Hirst Research Center, Wembley, England (1971)

25. J.D. Keller, "A Review of Soldering Technology and Related Areas," Martin Marietta Corp., Orlando, Fla. Reprinted by Hollis Engineering, Inc., Nashua, N.H. (April 1972)

26. K.G. Boynton, 'The Use of Oil Intermix in Wave Soldering," Hollis Engineering, Inc.

27. C.J. Thwaites, "Optimum Reliability in Printed Circuit Soldering Through Quality Assurance," Welding Journal (Oct 1972)

28. K.G. Boynton, "A Method for Holding Components for Automatic Lead Cutting and Wave Soldering," Hollis Engineering, Inc., Nashua, N.H.

29. "Omega Meter," Technical Bulletin, Kenco Alloy and Chemical Co., Inc., Addison, Ill.

TELEPHONE CONFERENCE REPORT

Conference Between

Author And:

a. Joseph Keller, Martin Marietta Co., Orlando, Fla., on 1 March 1976

b. Joseph Keller, Martin Marietta Co., Orlando, Fla., on 15 March 1976

c. Gordon Perkins, Supervisor of Inspection Engineering, Lockheed Missile and Space Co. (LMSC) on 12 April 1976

d. Dan Sisley, Supervisor of Test Measurement Technology (LMSC), on 12 April 1976

e. Frank Fichter, Supervisor of Manufacturing Research (LMSC), on 13 April 1976

f. Kenneth Boynton, President of Hollis Engineering Co., Nashua, N.H., on 29 April 1976

g. Warren Abbott, Hollis Engineering Co., Nashua, N.H., on 29 April 1976

UNCITED REFERENCES USED IN THE DEVELOPMENT OF BACKGROUND INFORMATION PERTINENT TO THE STUDY PROGRAM

Solderability

- "Symposium On Solder," STP 189, 1956 ASTM, 1916 Race St., Phil. 3, Pa.
- "Papers On Soldering," STP 319, 1962 ASTM, 1916 Race St., Phil. 3, Pa.
- Howard H. Manko, "Selecting the Right Solder Requires the Right Test Equipment," Alpha Metals, Jersey City, N.J.
- Howard H. Manko, "Mechanism of Wetting," Alpha Metals, Jersey City, N.J.
- "Standards on Solderability," RS-178 EIA, Electronic Ind. Assoc, 11 West 42nd St., New York, N.Y.
- R.M. Evans, "Solderability Tests and Requirements," Battelle Memorial Institute, Columbus, Ohio (April 1958)
- "An Apparatus for Testing the Solderability of Wire," Phillips Technical Review, Vol. 20, No. 6 1958-1959
- "Comparisons of Solderability," Institute of Metal Finishes, Vol. 36, 1959
- "Soft Soldering Manufacturing Process Development," Sandia Corp. (July 1965)
- "Waiter-There's A Fly in My Solder," Circuits Manufacturing (August 1974)
- D. Mackay, "The Solderability of Component Surfaces," General Electric Co., Ltd., Wembley, England
- F.J. Fuchs, "Solve Soldering Problems With Ultrasonics," Assembly Engineering (July 1972)
- AWS Conference Features "The Solder Connection," Assembly Engineering (June 1972)

- L.G. Snider, "Survey Study of Solder Fluxes," ARINC Research Corp., Santa Anna, Cal., IDEP Report No. 085.10.00.00-BG-01 (August 1967)

Wave Soldering

- R. Strauss and A.F. Barnes, "The Flowsolder Method of Soldering Printed Circuits," Electrical Engineering (Nov 1956)
- C.L. Barber, "Printed Circuit Soldering," Kester Solder Co., Chicago, Ill.

Reliability

- "Reliable Electrical Connections," RETMA, Chicago 1954 (Engineering Pub., Elizabeth, N.J.)
- "Reliable Electrical Connections," RETMA, Philadelphia 1956 (Engineering Pub., Elizabeth, N.J.)
- "Reliable Electrical Connections," RETMA, Dallas 1958 (Engineering Pub., Elizabeth, N.J.)
- "Reliable Electrical Connections," NASA (Soldering School), Marshall Space Flight Center, Huntsville, Ala.
- "Research Plus Training Equals Reliable Soldering," Production (Oct 1961)
- G.V. Browning and N.H. Bester, "Experimental Evaluation of Reliable Soldering Processes," (IEEE 1E. 79th St., New York, N.Y.)
- Dr. L. Pessel, "Assured Reliability in Solder Connection," Electronic Packaging (April 1961)
- V.O. Bryan, "Printed Circuit Board Evaluation," (Lockheed, CORLAC Jan 1966)
- J.T. Chasty, "Hidden Cause of Solder Connection Failures," (Lockheed - LMSC - March 1965)

- J.A. Bauer, "Reliability and Failure Rates of Permanent Electrical Connections," Martin Marietta Co., Orlando, Fla. (June 1966)

- E.R. Bangs and E.R. Beal, "Solder Cracking Study," RADC Final Report, Contract F30602-73-C-0171 (Sept 1974)

- R.N. Wild, "Fatigue Properties of Solder Joints," GIDEP Report No. 085.10.13.90-E7-01 (April 1972)

Design

- "Notes on Soldering," Tin Research Institute, 492 6th Ave., Columbus, Ohio

- "Handbook on Soldering," American Welding Society

- H. Manko, "How to Choose the Right Solder Flux," Alpha Metals, Inc., Jersey City, N.J.

- H. Manko, "How to Choose the Right Solder Alloy," Alpha Metals, Inc., Jersey City, N.J.

- H. Manko, "How to Design the Soldered Electrical Connection," Alpha Metals, Inc., Jersey City, N.J.

- "In Solder Flux Makes the Difference," Metal Progress (April 1961)

- "Basics of Soldering," American Machinist (1961)

- J.W. Buckelow and E.D. Knab, "Through Connections for Printed Wiring," Bell Labs Record (Oct 1958)

Training

- "Wiring and Soldering Reliability Through Formalized Training," Westinghouse Education and Training Center, Baltimore, Maryland

- J.D. Keller, "Development of High Quality Soldering," Martin Marietta, Orlando, Fla.

- S.W. Mahon, "School for Solderers, Old and New," Electronics (Sept 1961)

Inspection

- "Proceedings of the Ninth National Symposium on Reliability and Quality Control," IRE, ASQC, Jan 1963 (IEEE 1E. 79th St., New York 21, N.Y.)
- "Criteria for Soldered Interconnections Metallurgical Completeness" (1963 Symposium on Reliability and Quality Control, ASQC)
- "What Makes a Solder Joint Good?," Electronics (Nov 29, 1963)
- N.R. Srinivansan and H.S. Aswath, "The Significance of Contact Angle Measurements in Soldering," Journal of the Indian Institute of Science, Section B, Vol. 37, No. 4 (Oct 1955)
- "A Program to Develop a System for the Inspection of Soldered Electrical Joints," Final Report, Eastman Kodak Co. (Dec 1962)
- Soldering Inspection Manual, 00-15PA-1, NAVWEPS, Navy (U.S. Govt. Printing Office, Wash. D.C.)
- H. Manko, "Inspection and Quality of Solder Joints," Alpha Metals, Jersey City, N.J.
- "Circuit Analysis Checks PC Assembly Process," Assembly Engineering (May 1974)
- J.W. Kaufman, "Soldering and Welding Electronic Joints," Metal Progress (July 1970)

Workmanship

- "Selecting the Right Soldering Iron," Electronics (Feb 1961)
- "Good Tips for Your Soldering Iron," American Machinist/Metalworking Mfg. (March 1961)
- "Latest Soldering Irons Need Updated Mil Specs," Assembly Engineering (Dec 1974)
- "Tighter Control for Solder," Electronics (June 1971)

Testing

- "Testing: What the Future Holds," Electronic Packaging and Production, 1975

- J. Bobbin, "New Developments in Ultrasonic Testing," ASTM Standardization News (March 1975)

- J.R. Pivnichny and J.R. Skobern, "Four-Point Method Tests Solder Joints," Electronics (April 1975)

- J.D. Hislop, "Bonded Joints and Non-Destructive Testing," Non-Destructive Testing (June 1971)

- K. Kivenko and P.D. Oswald, "Some Quality Assurance Aspects of Automatic Testing," Journal of Quality Technology, Vol. 6, No. 3 (July 1974)

- J.E. Tomlin, "Accelerated Aging Forecasts the Service Life of Soldered Joints," Electronic Engineering (April 1971)

- "Nondestructive Evaluation," Rep. NMAB-252, National Academy of Sciences (AD-692491) (June 1969)

- Robert J. Collier, ; C.B. Burichardt; and L.H. Lin, <u>Optical Holography,</u> Academic Press, 1971

- <u>Non-Destructive Testing - Views, Reviews, Previews,</u> H.B. Egerton, ed., Oxford Univ. Press, 1969

- "Nondestructive Testing: Methods, Techniques and Their Applications," Rep. DDC-TAS-71-58-1, Defense Documentation Center (AD-733850), (Dec 1971)

- Harold Berger, <u>Neutron Radiography,</u> Elsevier Publishing Co., 1965

- Sigmund Berk, "Radiation Backscattering and Radiation-Induced X-rays for Measuring Surface Composition and Structure," Mat. Evaluation, Vol. 24, No. 6, June 1966, pp. 309-312

- <u>Research Techniques in Nondestructive Testing,</u> Roy S. Sharpe, ed., Academic Press, 1970

- Rudi Schroeer; Richard Rowand; and Harold Kamm, "The Acoustic Impact Technique – A Versatile Tool for Nondestructive Evaluation of Aerospace Structures and Components," Mat. Evaluation, Vol. 28, No. 11, Nov 1970, pp. 237-243
- Hugo L. Libby, Introduction to Electromagnetic Nondestructive Test Methods, Wiley-Interscience, 1971
- Ron Botsco, "The Eddy-Sonic Test Method," Mat. Evaluation, Vol. 26, No. 2, Feb 1968, pp. 21-26
- "Acoustic Emission," Spec. Tech. Publ. No. 505, ASTM, 1972
- Josef Krautkrammer, Ultrasonic Testing of Materials, Springer-Verlag, 1969
- Donald R. Green, "High Speed Thermal Image Transducer for Practical NDT Applications," Mat. Evaluation, Vol. 28, No. 5, May 1970
- W.R. Apple, "Infrared Nondestructive Inspection – A Status Report," Mat. Res. Standards, Vol. 9, No. 5, May 1969, pp. 10-13
- "The Laser Microprobe – A New Metallurgical Tool," Metals Rev., March 1965
- David P. Smith, "Analysis of Surface Composition with Low-Energy Backscattered Ions," Surface Sci., Vol. 25, 1971, pp. 171-191.
- S.C. Furman; R.W. Darmitzel; C.R. Porter; and D.W. Wilson, "Track Etching – Some Novel Applications and Uses," Trans. ANS, Vol. 9, No. 2, Nov 1966
- Robert C. McMaster; Merle L. Rhoten; and Jay P. Mitchell, "The X-Ray Vidicon Television Image System," Mat. Evaluation, Vol. 25, No. 3, March 1967
- "Acoustical Holography," Vol. 1, A.F. Metherell; H.M.A. El-Sum; and Lewis Larmore, eds., Proceedings of the First International Symposium on Acoustical Holography, Plenum Publishing Corp., 1969

- "Acoustical Holography," Vol. 2, A.F. Metherell and Lewis Larmore, eds., Proceedings of the Second International Symposium on Acoustical Holography, Plenum Publishing Corp., 1970
- "Acoustical Holography," Vol. 3, A.F. Metherell, ed., Proceedings of the Third International Symposium on Acoustical Holography, Plenum Publishing Corp., 1971
- R.T. Anderson and T.J. Delacy, "Nondestructive Testing Applications for Aerospace Materials and Components," Rep. GDC-ERR-1324, General Dynamics/Convair, Dec 1968, pp. 5, 1-7
- A. Vary, "Nondestructive Evaluation Technique Guide," Lewis Research Center, NASA, Washington, D.C., 1973

DATA SOURCES

- LMSC Technical Information Center
  Box 504
  Sunnyvale, Cal. 94088

- Lockheed Missiles and Space Co.
  Technical and Scientific Information Center
  3521 Hanover St.
  Palo Alto, Cal.

- Lockheed Georgia Co.
  Scientific and Technical Information Center
  86 Cobb Drive
  Marietta, Ga. 30060

- Lockheed Electronics Co.
  Technical Document Center and Library
  U.S. 22
  Plainfield, N.J. 07061

- Library of Congress
  Washington, D.C. 20541

- GIDEP Operations Center
  Corona, Cal. 91720

- Rome Air Development Center
  Griffis AFB
  N.Y. 13441

- National Research Council
  Ottawa, Canada KIAOR6

- Institute of Printed Circuits
  1717 Howard St.
  Evanston, Ill. 60202

DATA SOURCES (Cont)

- New Jersey Institute of Technology
  Robert W. Van Houten Library
  323 High St.
  Newark, N.J. 07102

- Rutgers University Library
  Library of Science and Medicine
  New Brunswick, N.J. 08903

- Plainfield Public Library
  Eighth St. and Park Ave.
  Plainfield, N.J. 07060

APPENDIX A

SUMMARY MATRIX

OF STUDY CONCLUSIONS

REJECTION CRITERIA

(a) Charring, Burning, or Other Damage To Insulation

Rationale: Indicates excessive heat was required to make joint possibly due to unclean parts.

Most Common Cause: Poor workmanship; i.e., carelessness.

Weighting: (Low) Most rejects would not result in failure.

Dynamic Test Confidence: (Low) Vibration may pick up gross failures (shorts).

(b) Splattering of Flux or Solder on Adjacent Connections or Components

Rationale: Solder splatters may break loose and cause shorts.

Most Common Cause: Poor workmanship.

Weighting: (Moderate) Splatters are common cause of intermittent failures.

Dynamic Test Confidence: (Moderate) Test under vibration in all three planes would increase the probability of detecting most shorts.

(c) Solder Points (Peaks)

Rationale: Peaks may reduce clearance between conductive elements on adjacent circuit board.

Most Common Cause: High surface tension of liquid solder.

Weighting: (Low) Most rejects would not result in failure.

Dynamic Test Confidence: (Low) Normal production hi-pot test would pick up as many areas of potential shorting.

(d) Pits, Scars, or Holes

Rationale: Defects may produce stress points that would result in cracks under vibration.

Most Common Cause: Related to the metallurgy of solder, and the combination of materials used in the soldering process.

Weighting: (Low) Most rejects would not cause failure.

Dynamic Test Confidence: (Low) Electrical measurement techniques are ineffective; thermal radiographic techniques require skilled visual analysis.

(e) Excessive Solder Which Obscures the Connection Configuration

Rationale: Masks possible damaged or birdcaged conductors.

Most Common Cause: Process control problems.

Weighting: (High) Makes visual determination of wetting and adhesion impossible.

Dynamic Test Confidence: (Low) No advantage over normal production testing is evident.

(f) Excessive Wicking

Rationale: Conductors will be rigidized and fatigue under vibration.

Most Common Cause: Will always occur unless anti-wicking tool used.

Weighting: (Low) Testing has been performed that indicates wicking is desirable if wires are soldered in their final orientation.

Dynamic Test Confidence: (Low) Vibration testing will shorten the life of all terminations.

(g) Loose Leads or Wires

Rationale: Will result in intermittent or open connection.

Most Common Cause: Poor workmanship, poor solderability.

Weighting: (High) Most rejects would result in failure.

Dynamic Test Confidence: (High) If tested under vibration in all three planes.

(h) Cold Solder Connections

Rationale: Joint will open during temperature change or vibration.

Most Common Cause: Low soldering temperature or inadequate soldering time.

Weighting: (Moderate) Defects cannot be visually detected, gold-rich joints, which always appear chalky, are commonly misclassified as cold solder joints.

Dynamic Test Confidence: (Moderate) Electrical tests under temperature and vibration may detect cold solder joints if circuit is functional and monitored during thermal excursion.

(i) Rosin Solder Connection

Rationale: Entrapped excessive flux has displaced solder, resulting in voids and weak connection.

Most Common Cause:
1. Unclean surfaces requiring excessive flux to produce wetting.
2. Poor workmanship.

Weighting: (Moderate) Most rejects could result in failure under operational levels of vibration.

Dynamic Test Confidence: (Low) Dynamic test levels of vibration may only degrade joint life without inducing failure during the test. Visual inspection is more effective.

(j) Fractured Solder Connection

Rationale: Joint will open under vibration.

Most Common Cause:
1. Mechanical stress on wire.
2. Forced cooling.

Weighting: (Low) Defect is seldom encountered.

Dynamic Test Confidence: (Moderate) Electrical tests may detect defect if circuit is functionally tested. Vibration may aggravate condition without causing failure during test.

(k) Cut, Nicked, or Scrapped Leads or Wire; Insufficient Slack

Rationale: Wires will separate and open under vibration.

Most Common Cause:
1. Poor workmanship during stripping.
2. Improper wire dress.

Weighting: (High) If termination unpotted.

Dynamic Test Confidence: (Low) Testing will not detect nicks.

(l) Unclean Termination (Lint, Residue, Dirt, Etc.)

Rationale: Dirt will act as moisture traps and may cause shorts. Dirt may contain ionizable salts that will cause corrosion if moisture is present.

Most Common Cause: Improper handling, storage and cleaning.

Weighting: (High) If term unpotted.

Dynamic Test Confidence: (Low) Electrical test may detect leakage but will not detect corrosion potential as a production test.

(m) Dewetting

Rationale: Indicates dirty or contaminated surface. Lack of adhesion will cause joint to fail.

Most Common Cause: Improper or inadequate cleaning or handling surfaces with greasy fingers prior to soldering.

Weighting: (High) Joint will probably fail.

Dynamic Test Confidence: (Moderate) I.R. tests may pick up high thermal resistance.

(n) Insufficient Solder

Rationale: Indicates weak connection subject to failure.

Most Common Cause: Careless operation.

Weighting: (Low) Most rejects would not result in failure.

Dynamic Test Confidence: (Low) I.R. test most effective.

(o) Visible Bare Primary Conductor Within Solder Joint Area

Rationale: Contaminated surfaces or insufficient solder resulting in dewetted or weak solder joint.

Most Common Cause: Improper cleaning prior to soldering.

Weighting: (High) If adhesion area reduced.

Dynamic Test Confidence: Same as (m).

(p) Clinched Leads Resulting in a Reduction of the Required Spacing Between Conductors

Rationale: Will result in leakage or breakdown failure.

Weighting: (High) Most rejects will fail electrically.

Dynamic Test Confidence: (Moderate) Hi-pot test will detect more rejects if conducted at elevated temperature.

(q) <u>Birdcaging</u>

Rationale: Individual strands are unsupported and will break under tension and flex.

Weighting: (High) If unpotted, (Low) if potted.

Dynamic Test Confidence: (Moderate) Noise tests under vibration may detect this condition if wires are poorly supported.

(r) <u>Splicing</u>

Rationale: Indicates unauthorized repair - reliability is degraded; quality is undetermined due to omission of inspection to an approved procedure.

Weighting: (Moderate) Most splices would not result in failure.

Dynamic Test Confidence: (High) I.R. thermal resistance test can detect poor splice.

(s) <u>Plated-Thru Holes Not Filled With Continuous Solder Plug</u>

Rationale: Plated-thru hole connection is mechanically weak.

Weighting: (Low) Contradicts test findings.

Dynamic Test Confidence: (N/A) Invalid criteria.

(t) <u>Dewetted Circuit Board Pads</u>

Same as (h) and (m) above.

(u)
(v) <u>Process Control Items</u> - Cannot be monitored by Functional Test.
(w)
(x)

PRINTED WIRING CRITERIA

(a) Pits, Scratches, Pinholes or 20% Undercut Patterns

Rationale: Defects will propagate under thermal stress and vibration and will result in "opens."

Weighting: (High) Solder is ineffective as a "crutch" for plating defects.

Dynamic Test Confidence: (High) Test levels can be increased to operational limits if performed on the test coupon without degrading the board.

(b) Separation of Conductor Pattern From Base Laminate

Rationale: Will result in opens after thermal and mechanical stress.

Weighting: (High)

Dynamic Test Confidence: (Low) Sample coupon tests may not detect this condition. Acoustical testing may be effective. Visual inspection required at present.

(c) Blisters in Conductor Pattern

Same as (b).

(d) Delamination of Base Material

Same as (b).

(e) Wrinkles in Conductor Pattern

Same as (b).

(f) Dirt, Grease, Etc. on Conductor Pattern

Rationale: Will result in dewetting.

Weighting: (High)

Dynamic Test Confidence: (Low) Solderability tests are more effective.

(g) <u>Scratched or Abraded Finish That Will Change Resistance</u>

Dynamic Test Confidence: (N/A) Resistance can be measured by normal production test methods.

MATRIX OF STUDY CONCLUSIONS*

DEFECT TYPE	PERCENTAGE OF DEFECTS THAT AFFECT RELIABILITY		PERCENTAGE OF DEFECTS THAT CAN BE DETECTED BY NORMAL (C&R) PRODUCTION TEST			PERCENTAGE OF DEFECTS THAT CAN BE DETECTED BY DYNAMIC TEST			TYPE OF TEST	TEST CONDITIONS	PERCENTAGE OF DEFECTS THAT CAN BE CONTROLLED BY PROCESS			PARAMETER CONTROLLED	EVALUATION METHOD OR PROCESS	PERCENTAGE OF DEFECTS FOR WHICH VISUAL INSPECTION IS EFFECTIVE		
	YES	NO	YES	NO	UNCERTAIN	YES	NO	UNCERTAIN			YES	NO	UNCERTAIN			YES	NO	UNCERTAIN
CHARRED INSULATION	10	90	-	95	5	5	70	25	HI-POT	VIBRATION	-	100	-	-	-	X	-	-
FLUX SPLATTER (RMA)	25	75	-	95	5	-	75	25	IR	TEMP	99	-	1	CLEANLINESS	OMEGA METER	-	50	50
FLUX SPLATTER (RA)	75	25	-	95	5	-	75	25	IR	TEMP	99	-	1	CLEANLINESS	OMEGA METER	-	50	50
SOLDER SPLATTER	90	10	55	5	40	80	5	15	HI-POT	VIBRATION	99	-	1	SURFACE TENS FLUX	PETROLEUM WAX, OIL	-	50	50
SOLDER PEAKS	10	90	2	95	3	2	95	3	IR	TEMP	99	-	1	SURFACE TENSION	TINNING OIL	80	10	10
POROSITY	1	99	-	100	-	-	99	1	IR	TEMP	50	25	25	FLUX	PETROLEUM WAX	80	15	5
EXCESSIVE SOLDER	50	50	-	98	2	-	99	1	IR	TEMP	99	-	1	SURFACE TENSION	PETROL WAX & OIL	20	75	5
WICKING	1	99	-	100	-	-	100	-	-	-	99	-	1	TEMP	HEAT SINK	-	50	50
LOOSE LEADS	-	100	90	1	9	98	1	1	CONTINUITY	VIBRATION	-	100	-	-	-	75	5	20
COLD SOLDER	-	100	-	99	1	-	50	50	PULSED LASER	TEMP	95	1	4	TEMP & SOLDERABILITY	MENISCOGRAPH	-	100	-
ROSIN SOLDER	90	10	50	40	10	75	20	5	CONTINUITY	TEMP & VIBRATION	99	-	1	SOLDERABILITY CLEANING	MENISCOGRAPH OMEGA METER	80	5	15
FRACTURED JOINT	80	20	40	40	20	50	30	20	IR	FUNCTIONAL TEST	95	4	1	PLATED THRU HOLE	CONTINUITY TEST WITH TEMP	1	98	1
NICKED LEADS	10	90	-	100	-	-	100	-	-	-	-	100	-	-	-	75	5	20
UNCLEAN TERM	50	50	1	95	4	5	80	15	IR	TEMP	99	-	1	CLEANING	OMEGA METER	-	50	50
DEWETTING	90	10	-	98	2	40	50	10	IR	TEMP	99	-	1	SOLDERABILITY	MENISCOGRAPH	80	1	19
INSUFFICIENT SOLDER	1	99	-	100	-	-	80	20	IR	TEMP	99	-	1	SOLDERABILITY, SURF TENS	MENISCOGRAPH OIL	80	20	20
IMPROPERLY CLINCHED LEADS	50	50	-	95	5	20	79	1	HI-POT	TEMP	100	-	-	CLINCHING NOT REQD	PETROLEUM WAX	50	45	5
PARTIALLY FILLED PLATED THRU HOLES	-	100	-	100	-	90	1	9	IR	TEMP	NOT REQUIRED			-	-	90	5	5
DEWETTED CIRCUIT STREETS	5	95	-	100	-	90	1	9	IR	TEMP	99	-	1	FLUX, SURF TENS, CLEANLINESS SOLDERABILITY	RA OR WAX OIL OMEGA METER MENISCOGRAPH	95	1	4

*All percentages are estimates based entirely on engineering judgment and opinions derived from the literature researched and technical discussions conducted as part of the study program

APPENDIX B

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
VISUAL–OPTICAL	Cracks, voids, pores, inclusions	Visual access required
	Roughness, grain, film	Specialized optical aids usually required
	(Mechanically aided) measurements	Various degrees of magnification required
	Visible responses to stress	Requires supplementation with other NDE techniques for flaw discrimination, detection, and measurement
		Hazard with ultraviolet light
HOLOGRAPHIC INTERFEROMETRY	Delaminations, lack of bond, or poor bond	Visual or optical access to test surface
	Macrostructural variations	Laser illumination must be adequate to field viewed
	Load response of structures; strain	Sensitive to half-wavelength surface displacements
	Stress concentrations; vibration analysis	Ambient micromovements and noise patterns interfere
		Optics or object isolation required to eliminate extraneous or ambient displacements; potential hazard from laser beam

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
LIQUID PENETRANT	Cracks, pinholes, laps, seams, coldshuts, leaks	Access required for surface decontamination and cleaning Discontinuity must be surface-connected and open Microcracks to order of 1-micrometer width False indications from shallow scratches and/or smearing Porosity of surface may mask important indications. Discontinuity depth is not indicated. Ultraviolet-light hazard (with fluorescent penetrants); vapor hazard.
FILTERED PARTICAL	Cracks and porosity	Clean and accessible surface required Test-object pore size should be less than 100 mesh Sensitive to microcracks to order of 100 micrometers Depth of flaw not indicated Residue removal required. Potential contamination. Cracks and/or pores must be open to surface. Skin irritants involved.

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
X-RADIOGRAPHY	Cracks, porosity, voids, and inclusions Internal malstructure, misassembly, or misalignment Thickness, diameter, gap, and position Density variations Wear and corrosion	Access to opposite sides of test object required Voltage, exposure time, and focal spot size critical Density and thickness variations to order to 2 percent Sensitivity decreases with increasing thickness Cracks must be oriented parallel to beam. Radiation hazard.
NEUTRON RADIOGRAPHY	Voids, porosity, inclusions, and cracks Internal malstructure, anomalies, and/or misalinement	Access to interpose object between source and detectors Collimation, filtering, and moderation of neutron beam Density or thickness variations to order of 2 percent Sensitivity decreases with increasing thickness Cracks must be oriented parallel to beam. Image quality varies with neutron source. Radiation hazard.

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
PENETRATING RADIOMETRY	Voids, inclusions, and porosity	Access of interpose object between source and detector Beam size and alinement critical Transmission variations to order of 0.2 percent Nature of flaw may be ambiguous as a result mixed effects Beta radiation applies to ultrathin sheet and coatings. Radiation hazard.
RADIOACTIVE GAS PENETRANT	Cracks and pores Oxidation and corrosion Friction, wear, erosion, and abrasion effects	Surface cleaning and penetration method critical Flexible photoemulsion base or spray coating Crack width to order of 0.01 micrometer Extremely sensitive to spurious mars and scratches Flaw depth must be inferred. Radiation hazard, requires gas recovery system.

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
RADIOACTIVE GAS PENETRANT (Cont)	Cracks, inclusions, gouges, scratches, holes, and pores	Very near proximity of probe to surface
	Compositional variations	Specialized probes usual for various measurements
		Cracks to order of 0.03 millimeter
		Ambiguities arise because of edge and/or lift-off effects
		Access to both sides for some thickness measuring; does not discriminate among types of flaws
ELECTRIC CURRENT	Cracks and inclusions	Good surface contact required
	Segregations and grain orientation	Electrode or probe spacing and contact critical
	Thickness variations	Can indicate (relative) depth of cracks
	Resistivity, conductivity	Dependent upon shape and orientation of discontinuity
		Edge-effects and contamination of surface limit utility; may mar surface

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
ELECTRIFIED PARTICLE	Cracks, pinholes, and crazing	Surface must be carefully cleaned and dried
		Flaw must be surface connected
		Cracks to order of 0.1 micrometer wide
		False indications caused by high humidity, moisture streaks, lint, and improper cleaning and/or drying
		Poor resolution on thin coatings; high-voltage discharge but slight shock
ACOUSTIC IMPACT	Cracks, debonds, and delaminations	Contact, fixturing, and support of object required
	Macrostructural variations and anomalies	Pulser design and impact point critical
	Variations of physical dimensions	Low spatial resolution to order of centimeters
		Sensitive to ambient and extraneous noise and signals
		Mass and/or complexity and impact point influence results. All physical and geometric properties but the one tested must be constant.

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
PULSED ECHO ULTRASONICS	Cracks, voids, laminations, inclusions, and debonds	Access to one side and liquid coupling to object
	Porosity; metallurgical structure and graininess	Special probes, coupling, and alinement fixtures usual
	Thickness	Flaws to order of 0.01 millimeter in size
	Crack growth	Ambiguous signals may arise as a result of scatter effects, multiple reflections, and geometric complexity
		Small or thin parts are difficult to inspect
TRANSMISSION ULTRASONICS	Cracks, voids, laminations, and inclusions	Coupling and access to two sides
		Selection, alinement, and fixturing of probes
		Flaws to order of 0.2 millimeter
		Spurious signals may arise as a result of reflections, dispersion, or resonance
		Poor results unless surfaces are uniform and parallel and only one type of defect is present

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
SURFACE-WAVE ULTRASONICS	Cracks	Contact or coupling with surface
	Roughness, scratches, and graininess	Special angle blocks or wedges required for probe
	Incipient cracking	Minute surface cracks to order of 0.1 millimeter deep
		Very sensitive to surface roughness
		Surface waves can be dampened by water, oil, dirt, and/or fingerprints
INFRARED RADIOMETRY	Lack of bond, imbedded material, voids, and porosity	No contact; emissivity coatings may be required
	Temperature	Fixturing for heating and cooling required; orthogonal view of surface preferred
	Heat-transfer characteristics, fatigue cracking and hot spots	Temperature variations to order of 1°C
		Poor resolution of flaw area with thick specimens
		Locates flaw areas; no indication of nature of flaw

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
THERMOCHROMIC	Cracks and lack of bond Hot spots, and poor contact	Surface access required for cleaning and coating Fixturing for proper heating of test object Temperature difference to order of 0.1°C Critical time-temperature relation
ELECTRO THERMAL	Voids, cracks, and inclusions	Visual access to surface and electrode contact required Electrode contact and spacing tailored to part Cracks to order of 0.03 millimeter Requires combination with other thermal techniques for flaw detection Part should be uniform in region of interest Sensitivity to thickness variations.

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
PULSED LASER PROBE	Cold solder joints, intermittents	Optical view and access to surface required
	Analysis and distribution of elements and impurities	Focusing and microminiaturization of beam diameter
		Analytical accuracy to order of 5 percent
		Depends on control and reproducibility of laser beam diameter and energy
		Minute amount of material removed
	Cracks, inclusions, porosity, voids, and lack of bond	One-side access of autoradiography; two if external source
	Misalinement and/or malstructure	Special filters, screens, and/or scintillators needed for image quality
FILM RADIOGRAPHY	Thickness, diameter, position, and spacing	Resolution ranges to order of 2000 line pairs per centimeter
		Image quality impaired by scatter radiation and finite source or focal-spot-size gamma fogging; requires control of chemicals and photoprocessing conditions for reproducible results

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
XERORADIOGRAPHY	Cracks, inclusions, porosity, voids, and lack of bond Misalinement and/or malstructure Thickness, diameter, position, and spacing	Access to two sides of test object required Practical voltage limited to less than 100 kV Thickness sensitivity to order of 2 percent Xeroradiographic plates are easily damaged Powder- and/or layer-deficient dots and other artifacts hamper image interpretation
TRACK-ETCH RADIOGRAPHY	Voids, porosity, and inclusions	Access to both sides of test object required Foil transfer methods, as in neutron radiography, required Resolution to order of 0.01 millimeter Low-contrast image produced requires contrast-enhancement Experimental technique

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
FLUOROSCOPY	Cracks, porosity, voids, and inclusions	Access to two sides of test object required
	Macro-malstructure and misalinement	Fluoroscopic enclosure limits object size
	Thickness, diameter, spacing, and position	Considerably lower resolution than film radiography
	Density variations	Requires low ambient lighting and eye accommodation
	Effects of distorting forces; dynamic phenomena	Image quality hampered by screen unsharpness, attenuation by windows and mirrors, and fluorescence fluctuations
VIDEO RADIOGRAPHY	Voids, porosity, inclusions, and cracks	Access to interpose object between source and detector
	Malstructure and/or misalinement	Useful apertures limited to order of several centimeters
	Dimensional variations	Thickness variations to order of 4 percent
		Usually limited to coarse indication of flaws
		Inferior to film radiography for fine cracks

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
IMMERSION ULTRASONICS	Cracks, voids, laminations, debonds, and inclusions	Liquid immersion and access to at least one surface required Small, thin, rough-surface parts are difficult to evaluate Discontinuities to order of 0.01 millimeter Ambiguous response from scatter and geometric complexity Geometrically complex and/or non-regular objects require intricate scanning arrangements
ULTRASONIC VIDEOGRAPHY	Debonds, lack of bond, delaminations Microporosity; grain and crystalline structure	Immersion of test object required Crystal (diameter) limits area view to order of few centimeters Typical sensitivity to order of 0.1 centimeter Ambiguous response from interference fringes due to Fresnel-Fraunhofer effects

SUMMARY OF NONDESTRUCTIVE MEASUREMENT TECHNIQUES (Cont)

MEASUREMENT TECHNIQUE	TYPE OF DEFECT DETECTABLE	LIMITATIONS
ULTRASONIC HOLOGRAPHY	Cracks, debonds, voids, and inclusions	Specimen or test object immersion in liquid required
	Malstructure and/or misalinement	Limited area of object viewable due to transducer size
		Spatial resolution to order of 1 millimeter
		Scatter or attenuation can seriously limit utility
		Size of defectable flaw increases with increasing thickness of object
VIDEO THERMOGRAPHY	Delaminations, debonds, and porosity	Visual access to surface required
	Thermal-conductivity variations	Mode and/or uniformity of heat application critical
	Thermal mapping	Temperature variation to order of 0.1°C
		Detector response in wide temperature range in nonlinear
		Relatively slow response to thermal fluctuations

APPENDIX C

SUGGESTED TEST PROGRAM FOR EVALUATING SOLDER JOINT STUDY FINDINGS

PHASE II - SOLDER JOINT TEST AND EVALUATION PROGRAM

OBJECTIVE

The objective of the test program is derived from a distillation and evaluation of the information reviewed in the literature search and study phase of the program. The initial conclusion which is based on the study findings is that better and cheaper solder joints can be obtained by utilizing a soldering process based on rigid process control in conjunction with abbreviated visual inspection. This conclusion will be tested by comparison with joints obtained by using 100% visual inspection based on MIL-STD-1460.

The major objective of the test program will be to evaluate the philosophies described above by performing soldering operations on the test boards under varying process control conditions, performing thorough inspections of these boards and then subjecting the boards to various types of dynamic testing i.e., thermal cycling, shock and vibration testing, and pull testing. The test boards will be carefully monitored throughout the entire assembly, cleaning, soldering, post-solder cleaning, testing and final evaluation phases.

TESTING TO BE PERFORMED

Tests will be performed on specially designed printed wiring board assemblies under varying process control conditions. The boards will then be subjected to dynamic stress testing. This is described in detail as follows:

TEST BOARD DESIGN

The test printed wiring board shall be designed as a double sided board and will mount a variety of components including integrated circuits, resistors, diodes, capacitors, and wires for pull testing. It shall also contain a large number of plated-thru holes without component leads in them. Hole sizes shall be varied in order to be able to evaluate whether there is any proper relationship between component lead diameter and hole diameter. Annular ring sizes shall be varied and concentricity between holes and pads shall be varied in order to determine if there is any real significance to minimum annular ring requirements. Component leads will be both clinched and unclinched in order to determine relative advantages or trade-offs. The board shall also

contain a functioning circuit to enable electrical testing to be performed. Approximately 100 boards will be required for testing.

SOLDERING TESTS

The test boards shall be soldered under a variety of process control conditions in order to evaluate the impact of various forms of process control on the quality of the solder joints. Tests to be performed include the following:

Standard Wave Soldering

Twenty boards shall be assembled and soldered in accordance with MIL-STD-1460 utilizing normal, existing assembly and wave soldering techniques. Type RMA flux shall be used.

Standard Wave Soldering Using RA Flux

Ten boards shall be assembled and soldered utilizing process controls and normal, existing assembly and wave soldering techniques except that type RA flux shall be used and special cleaning and testing shall be used after soldering.

Wave Soldering Based on Meniscograph Testing

Ten boards and their designated components shall be tested using a meniscograph in order to evaluate the solderability of the boards and the components. Based on the results of the meniscograph tests the type of solders and flux to be used shall be determined. The boards shall then be assembled and wave soldered utilizing normal production techniques except that the solder and flux as determined by prior meniscograph testing shall be used. The boards and components shall be carefully tracked and monitored to see if the meniscograph can predict which boards and components will solder well and which ones will solder poorly.

Wave Soldering Using Water-Based Flux

Duplicate the test described above except that a water-based flux and a controlled water-based cleaning process shall be used.

Wave Soldering Using Oil Infiltration Process

Duplicate the tests described on page 153, except that wave soldering shall be performed using new wave soldering machines having an oil infiltration process which is claimed to improve the wetting of the solder and also reduce icicling.

Wave Soldering Using the Wax Stabilizer Process

Duplicate the test described on page 153 except that component leads shall not be clinched or cut since the wax stabilizer machine shall be used to secure and flux the leads. After the leads have been secured by the wax stabilizer they shall be automatically trimmed to a proper length and 10 boards shall be flow soldered on a wave soldering machine using the oil infiltration process, and 10 boards shall be flow soldered without the use of oil.

Repeat Testing

Ten circuit boards shall be held in reserve and shall be used to repeat testing as required.

PROCESS CONTROL STANDARDS

In order to insure that proper care and controls are exercised throughout the testing described above, procedures and process controls as described below shall be obtained or prepared and followed throughout testing.

PROCESS CONTROL FOR THE INSPECTION AND ACCEPTANCE TESTING OF PRINTED CIRCUIT BOARDS

A process control standard shall be prepared defining solderability and cleanliness test requirements and methods for P.C. boards. Dynamic testing for evaluating the acceptability of plated-thru holes will also be defined.

PROCESS CONTROL FOR DETERMINATION OF SOLDERABILITY

A process standard shall be prepared describing the proper use of the Meniscograph and other equipment used in determining the solderability of components and circuit boards.

PROCESS CONTROL FOR STANDARD PRODUCTION WAVE SOLDERING

The documents used for process control of standard production wave soldering equipment aimed at satisfying MIL-STD-1460 inspection criteria shall be reviewed in detail and upgraded as applicable with the additional controls required for this test program.

PROCESS CONTROL FOR USE OF RA FLUX

A process standard for use of RA type flux in wave soldering shall be prepared and used as applicable in testing.

PROCESS CONTROL FOR USE OF WATER-BASED FLUX

A process standard shall be prepared for use of water-based flux with the wave soldering machine. The standard shall also include instructions for cleaning before and after soldering.

PROCESS CONTROL FOR USE OF THE OIL INFILTRATION PROCESS

A process standard shall be prepared for using the Oil Infiltration process in conjunction with the wave soldering machine.

PROCESS CONTROL FOR USE OF THE WAX STABILIZER PROCESS

A process standard shall be prepared for use of the wax stabilizer process in conjunction with the wave soldering machine.

PROCESS CONTROL FOR EVALUATING CLEANLINESS

A process control standard shall be prepared defining methods for evaluating P.C. boards and components for cleanliness in accordance with MIL-P-28809.

INSPECTION STANDARDS

In order to evaluate the value of inspecting solder joints using standard (MIL-STD-1460) visual inspection criteria versus new abbreviated visual criteria, explicit inspection standards in check list form shall be prepared. Each board shall have its own check list which shall accompany it throughout assembly, soldering and testing of the boards. The check list will form a

permanent record of joint quality and history. Particular attention shall be paid to establishing the new abbreviated visual inspection criteria, including the development of visual aids. The standards shall define such qualities as porosity, wetting, voids, shrink lines, etc., and how they are applied to the visual inspection of solder joints.

DYNAMIC TESTS

Stress testing including thermal cycling, vibration testing, pull testing and accelerated life testing will be used to determine the true value of visual inspection criteria. All joints will be monitored electronically and watched closely throughout testing, especially those determined by visual inspection to be of inferior quality. The stress testing will attempt to induce failures. Specific types of stress testing to be performed are described below.

THERMAL CYCLING TESTS

Two boards from each of nine groups shall be thermally cycled to typical hardware requirements and two boards from each of nine groups shall undergo destructive thermal shock cycling. Specific tests to be performed are described below.

Typical Hardware Thermal Cycling

Cycle boards between -65°F and +160°F per MIL-STD-810, method 503.

Destructive Thermal Shock Cycling

Cycle boards between -85°F (15 minute soak) and 300°F (15 minute soak) allowing no more than one minute between temperature changes. The number of cycles shall be sufficient to induce an adequate number of electrical failures for analysis (approximately 100 cycles).

VIBRATION TESTS

Two boards from each of nine groups shall be vibration tested to typical hardware requirements, and two boards from each group shall undergo destructive vibration testing. Specific tests to be performed are described below:

Typical Hardware Vibration Testing

Boards shall undergo transportation vibration testing between 5 and 500 cps at both -65°F and 160°F as described in paragraph 3.17 of PA-PD-1205B.

Destructive Vibration Testing

Boards shall be cycled in a plane perpendicular to the plane of the board in order to determine the resonant frequency of the board. The boards shall then be vibrated at resonance until a sufficient number of solder joint electrical failures occur.

PULL TESTING

Pull testing shall be performed on two each of nine groups of boards i.e., one board from each group that had undergone transportation vibration testing and one board from each group that had undergone thermal cycling. Force values shall be recorded for each joint pulled.

ACCELERATED LIFE TESTS

Accelerated life tests at 160°F and 95% RH shall be conducted on the two boards from each group of nine that exhibited the best performance to determine if anything in each of the nine different ways of processing the boards might impact the long term reliability of the boards, components or solder joints. The remaining two sample boards will be conformally coated and stored under normal conditions for future reference.

INSPECTION TESTS

Inspection tests shall be performed in order to determine solder joint failure. Tests shall be electrical and visual.

ELECTRICAL TESTS

Electrical tests will be performed on all the boards before and after the stress tests discussed in the preceding pages. Tests to be performed will include functional tests, continuity tests, and resistance tests. It is anticipated that solder joint failure will show up as either an electrical open or as a significant change in resistance. It is also planned that functional electrical tests will be performed while the test boards are undergoing thermal and vibration testing.

VISUAL TESTS

Visual tests shall be performed before, during and after stress testing to spot solder joint failure as evidenced by cracks. Microscopic examination of joints shall also be performed in order to spot cracked joints. Some failed (cracked) joints shall be sectioned in order to analyze the propagration of the crack.

AREAS OF EVALUATION

The primary purpose of this investigation is to evaluate the importance of specific visual inspection criteria and specific forms of processing and processing controls. Key areas which will be evaluated throughout the investigation include the following:

a. The significance of cosmetic inspection criteria, including:

1. Voids, pits, holes and porosity in solder joints

2. Shrink lines on shrink cavities in solder joints

3. Discoloration of solder and surface brightness

4. Wicking of solder up wires

5. Nicked wires and nicks covered with solder

6. Insufficient solder in holes and around component leads

7. Plated-thru holes which are partially filled with solder

8. Insufficient annular ring

9. Entrapped oil and or flux in solder joints

b. The significance of the new abbreviated visual inspection criteria, including:

1. Sufficient area of solder adhesion

2. Sufficient evidence of wetting

3. Inspection of 1 and 2 on the bottom side of board only

c. The significance of clinched versus unclinched leads

d. The significance of properly sizing the hole to the component lead diameter

e. The following processes and equipment will also be evaluated:

1. The oil intermix process

2. The use of the Meniscograph to determine if good wetting is occurring and its value in selecting the proper flux and solder to be used

3. The wax stabilizer process

4. The value of using activated (RA) and water-soluble fluxes

5. Cleaning process to be used with activated (RA) and water-soluble fluxes

6. The use of the Omega meter to monitor ion concentration and determine the cleanliness of boards before and after assembly

COST SAVINGS ANALYSIS

An additional objective of this study will be to perform a cost analysis of manufacturing and inspecting solder joints using the existing (MIL-STD-1460) 100% visual inspection criteria versus the new process controls and abbreviated visual inspection criteria. The cost of new equipment, i.e., Meniscograph, wax stabilizer, oil intermix mechanism, Omega meter, etc., will be included.

ANTICIPATED COST SAVINGS FROM USING SIMPLIFIED VISUAL INSPECTION TECHNIQUE

It is anticipated that use of a simplified visual inspection technique coupled with improved processing will result in a substantial cost saving in inspection costs. A comparison of the attributes presently inspected with those to be inspected using the simplified visual inspection technique is detailed in Table A. It should be noted that the presently used method of inspection requires the use of a 6X to 10X magnification whereas the simplified technique does not require the use of magnification.

The reason that the use of the simplified inspection technique is expected to be more effective is because most of the critical subjective aspects of visual inspection are eliminated. Extra effort must be expended in processing, such as the use of solderability measurement techniques (use of Meniscograph), use of the oil intermix process, use of proper flux (RA when required), proper cleanliness controls, use of the wax stabilizer process, etc. The extra processing is expected to insure the production of high quality solder joints.

The test program will provide useful data for determining the cost savings that can be realized by a controlled process and simplified visual inspection technique. At present, certain estimates can be made as shown below:

a. Save 50% of present cost inspecting bottom side of board only

b. Save additional 20%–25% because of simplified inspection

c. Save additional 10–15% due to reduced rework and reinspection costs

Total estimated savings would be 80%–90% of present inspection costs; this would represent .8 to .9 hours per typical printed circuit board assembly.

APPROXIMATE COST OF CAPITAL INVESTMENT IN PROCESS CONTROL EQUIPMENT

a.	Cost of meniscograph	\$ 5,000
b.	Cost of wax stabilizer	\$35,000
c.	Cost of Omega meter	\$ 7,400
d.	Cost of oil intermix and new wave solder machine	\$10,000

ANTICIPATED NET SAVINGS IN OVERALL PRODUCTION COSTS

There would also be some cost to operate the new processing equipment. It is estimated that there would be a 10% increase in overall operator costs or approximately .1 hour of additional time per typical pwb. Net savings per board would then be approximately .7 to .8 hour.

Table C-1. Comparison of inspection criteria

Visual Inspection Criteria	Required Per MIL-STD-1460(MU)*	Simplified Visual Inspection Method**	Process Control Sample Test
1. Check all joints for evidence of wetting and adherence (fillet)	X	X	
2. Check all joints for cleanliness	X		Omega Meter Per MIL-P-28809
3. Check for flux spatter	X		Omega Meter Per MIL-P-28809
4. Check for solder spatter	X	X	
5. Joints must be uniformly bright in color	X		
6. Joints must be free of peaks and protrusions	X	(X) Per Minimum Height Reg on Drawing	
7. Joints must be free of pinholes and voids	X		
8. Solder must fill plated-thru holes	X		

Table C-1. Comparison of inspection criteria (Cont)

Visual Inspection Criteria	Required Per MIL-STD-1460(MU)*	Simplified Visual Inspection Method**	Process Control Sample Test
9. Solder fillet must surround component lead 360°	X		
10. Wicking on wires cannot extend beyond insulation	X		
11. Disturbed solder joints are not permitted	X		
12. Flux inclusions are not permitted	X		Omega Meter Per MIL-P-28809
13. Porosity is not permitted	X		
14. Excess solder is not permitted	X	X	
15. Solder bridges between circuitry is not permitted	X	X	
16. Cracks are not permitted	X	X	
17. Scars and dents are not permitted	X		
18. No dewetting of conductive areas	X		

*Inspection Performed on Both Sides of Board with 6X to 10X Magnification.
**Inspection Performed on Bottom Side of Board only with no Magnification.

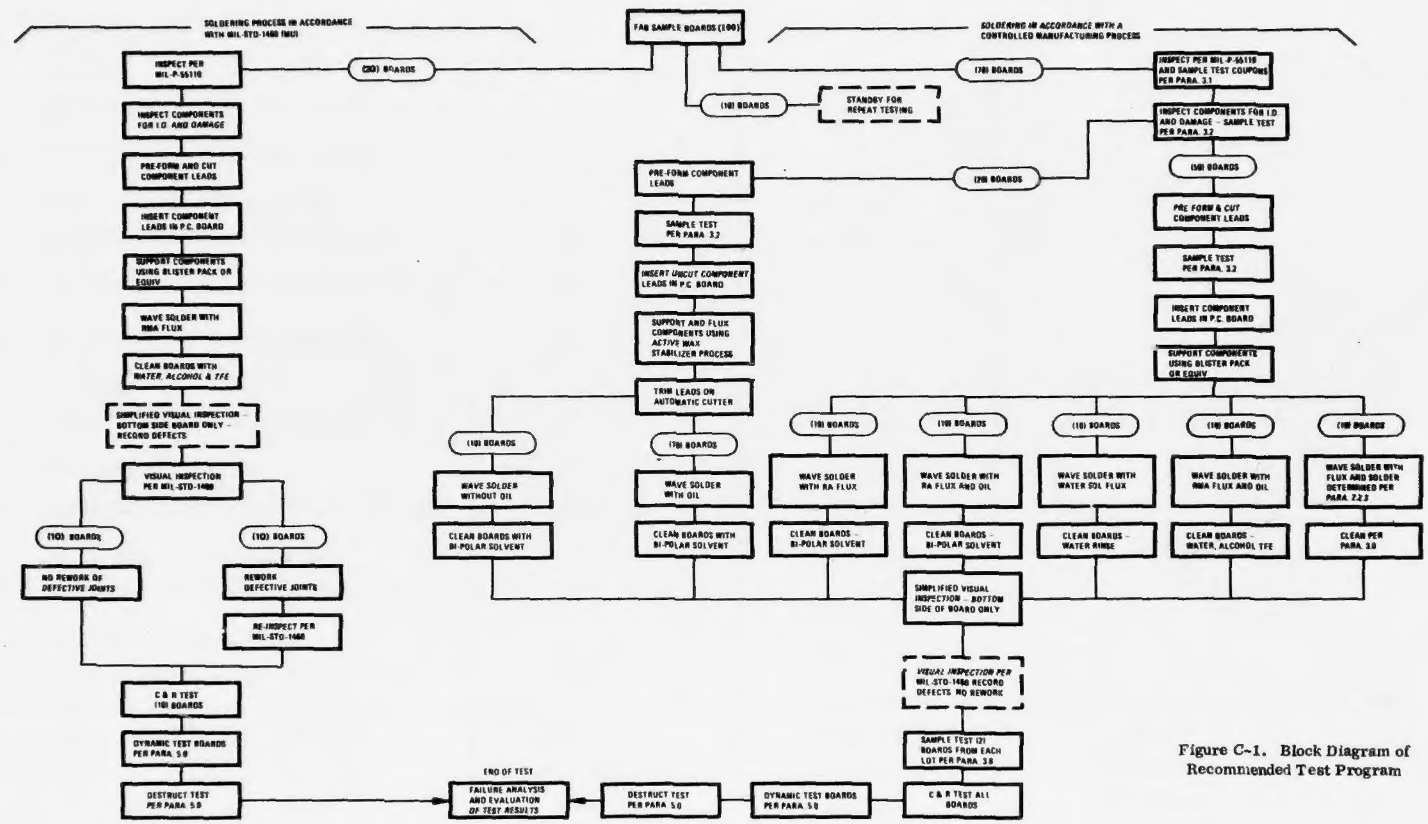


Figure C-1. Block Diagram of Recommended Test Program

DISTRIBUTION	COPY NO.
Commander US Army Materiel Development and Readiness Command ATTN: DRCQA 5001 Eisenhower Ave. Alexandria, Virginia 22304	1
Project Manager for Nuclear Munitions US Army Materiel Development and Readiness Command ATTN: DRCPM-NUC Dover, New Jersey 07801	2-3
Commander US Army Armament Command ATTN: DRSAR-QA Rock Island, Illinois 61201	4
Defense Documentation Center Cameron Station ATTN: DDC-TCA Alexandria, Virginia 22314	5-16
Commander Picatinny Arsenal	
ATTN: SARPA-COT	17
SARPA-IO	18
SARPA-ND	19-23
SARPA-QA	24
SARPA-QA-A	25
SARPA-QA-I	26
SARPA-QA-N	27-31
SARPA-TS-S	32-36
SARPA-TS-X	37
Dover, New Jersey 07801	